DESCRIPTION

OPTICAL INFORMATION RECORDING MEDIUM AND OPTICAL RECORDING METHOD

TECHNICAL FIELD

5   The present invention relates to an optical information recording medium for high density recording having a phase-change type recording layer, such as a rewritable DVD, and an optical recording method. Particularly, it relates to an optical information

10   recording medium and an optical recording method, whereby the linear velocity dependency and the recording power dependency at the time of one-beam overwriting and the stability with time of recorded marks, are improved.

BACKGROUND ART

15   With a compact disk (CD) or DVD, it is common that recording of binary signals and detection of tracking signals are carried out by utilizing a change in reflectance caused by interference of reflected lights from the mirror surface and the bottom of pits.

20   In recent years, phase-change type rewritable compact disks (CD-RW, CD-Rewritable) have been widely used as media interchangeable with CD. Further, also with respect to DVD, various proposals have been made for phase-change type rewritable DVD.

25   Such phase-change type rewritable CD and DVD utilize a change in the phase difference and the difference in reflectance caused by a difference in the refractive

index as between an amorphous state and a crystalline state for detecting recording information signals. A usual phase-change medium has a structure comprising a substrate, and a lower protective layer, a phase-change recording layer, an upper protective layer and a reflective layer, formed on the substrate, whereby multiple interference of these layers can be utilized to control the difference in reflectance and the phase difference and to provide CD or DVD with interchangeability.

With CD-RW, within a range where the reflectance is lowered to a level of from 15 to 25%, interchangeability with a CD in the recording signals and the groove signals can be secured, and retrieving can be carried out by a CD drive having an amplifying system added in order to complement the low reflectance.

With a phase-change recording medium, erasing and rewriting can be carried out simply by modulating the intensity of a single laser beam. Accordingly, with a phase-change recording medium such as CD-RW or rewritable DVD, recording includes overwriting wherein recording and erasing are carried out at the same time.

For information recording utilizing a phase-change, it is possible to employ a crystal state, an amorphous state or a mixed state thereof, and a plurality of crystal phases may also be used. However, with rewritable phase-change recording media which are

presently practically used, it is common that an unrecorded or erased state is a crystal state, and recording is carried out by forming amorphous marks. As a material for the recording layer, it is common to

5 employ a chalcogen element, i.e. a chalcogenide alloy containing S, Se or Te.

For example, it may be a GeSbTe type containing, as the main component, a $GeTe-Sb_2Te_3$ pseudo binary alloy, an InSbTe type containing, as the main component, an $InTe-$

10 Sb_2Te_3 pseudo binary alloy, a AgInSbTe type alloy containing, as the main component, eutectic crystal of $Sb_{0.7}Te_{0.3}$, or a GeSnTe type.

Among them, a system having excess Sb added to a $GeTe-Sb_2Te_3$ pseudo binary alloy, particularly, an

15 intermetallic compound neighborhood composition such as $Ge_1Sb_2Te_4$ or $Ge_2Sb_2Te_5$, has been mainly practically used.

Such a composition is characterized by crystallization accompanying no phase separation which is specific to an intermetallic compound and has a high

20 crystal-growth rate, whereby initialization is easy, and the recrystallization speed at the time of erasing is high. Therefore, as a recording layer showing practical overwriting characteristics, an attention has been drawn only to a pseudo binary alloy system or an intermetallic

25 compound neighborhood composition (Jpn. J. Appl. Phys., vol. 69 (1991), p 2849 or SPIE, Vol. 2514 (1995), pp 294-301).

On the other hand, with such a composition, metastable tetragonal system crystal grains will grow. Such crystal grains show distinct grain boundaries, and their sizes are not uniform and optical anisotropy is

5   remarkable depending upon the orientation. Accordingly, there is a problem that optical white noises are likely to be generated.

Such crystal grains different in the particle sizes and optical properties, are likely to grow around

10 amorphous marks, whereby there will be a problem that jitter of mark is likely to increase, or the optical characteristics are different from peripheral crystals, whereby they are likely to be detected as non-erased portions.

15 Accordingly, there has been a problem that it is impossible to obtain good retrieving characteristics in recording at a high linear velocity or in high density mark length modulation recording. Specifically, according to the specification for rewritable DVD, the

20 shortest mark length is 0.6 μm, but if the shortest mark length is further decreased, jitter has been found to increase abruptly.

As a method for reducing jitter, there is so-called absorptivity correction. With a conventional four-layer

25 structure, light energy absorbed by a recording layer is usually such that light energy Ac absorbed in a crystal state having a high reflectance is smaller than light

energy Aa absorbed in an amorphous state having a low reflectance (Ac<Aa). Therefore, there is a problem that depending upon whether the original state was a crystal state or an amorphous state at the time of overwriting,

5   the shapes, etc., of newly recorded marks are different, whereby jitter will increase.

Here, by adjusting the absorptivity of light energy in the crystal state and in the amorphous state to be substantially equal, the mark shape may be stabilized

10   irrespective of the original state, whereby jitter can be reduced. Further, crystal requires an extra heat corresponding to the latent heat at the time of melting, and accordingly, it is preferred to adjust so that light energy is absorbed more in the crystal state (Ac>Aa).

15   To accomplish this relationship, a method may be mentioned wherein at least one layer of light absorptive nature is added to make a structure of at least 5 layers, so that part of light absorption in the amorphous state is absorbed by this absorptive layer. For example, an

20   absorptive layer of e.g. Au or Si is inserted between the lower protective layer and the substrate or on the upper protective layer (Jpn. J. Appl. Phys., vol. 37 (1998), pp 3339-3342, Jpn. L. Appl. Phys., Vol. 37 (1998), pp 2516-2520).

25   However, such a layer structure creates a problem in the heat-resisting property or the adhesion of the absorptive layer, whereby deterioration such as

microscopic deformation or peeling tends to be remarkable by repetitive overwriting. Further, the storage stability is likely to be impaired, since peeling or the like is likely to occur.

5   Namely, it has been difficult with a GeTe-Sb$_2$Te$_3$ pseudo binary alloy recording layer to accomplish high densification while maintaining a conventional four-layer structure.

Further, with the GeTe-Sb$_2$Te$_3$ pseudo binary alloy
10   recording layer, the birefringence has a wavelength dependency such that the shorter the wavelength, the smaller the real part and the larger the imaginary part. Accordingly, especially when a short wavelength laser beam is employed as a light source, it is difficult to
15   accomplish the condition of Ac>Aa.

Therefore, in recent years, a AgInSbTe four component alloy has been employed as a material for the recording layer. The AgInSbTe four component alloy has a feature that an erasing ratio as high as 40 dB can be
20   obtained, whereby a high linear velocity and high density mark length modulation recording can be carried out with the conventional four-layer structure without absorptivity correction.

However, high speed recording usually means that the
25   crystallization speed is high and the recorded information is easily erased, whereby amorphous marks are likely to be crystallized and the stability of recorded

marks with lapse of time is poor in many cases.

Further, a medium which is capable of recording and
retrieving information at a high speed, has been demanded
recently in order to shorten the time for recording or to
5   speed up the transmission of information, as the quantity
of information has increased. For example, a standard
speed of CD (1-time velocity) is from 1.2 to 1.4 m/s.
Whereas, CD-RW capable of recording at a speed as high as
4-times velocity has been commercialized, and CD-RW
10   capable of recording at a speed as high as 8- to 10-times
velocity is now desired.

On the other hand, as rewritable DVD, various types
have been proposed or commercialized including DVD-RAM,
DVD+RW and DVD-RW. However, rewritable DVD with 4.7 GB
15   which is a capacity equivalent to read-only DVD, has not
yet been practically developed.

Namely, a medium which is excellent in stability of
marks and capable of recording short marks at a high
speed is demanded.

20   However, it has been believed that the high speed
recording and the stability of marks are incompatible
properties and it is difficult to satisfy both of them at
the same time.

The present inventors have extensively studied the
25   principle of crystallization and conversion to amorphous
state, and as a result, found an epoch-making medium
satisfying all these properties at the same time.

Namely, it is an object of the present invention to provide an optical information recording medium which is capable of recording short marks very well at a high speed and excellent in the stability of marks, and an
5 optical recording method.

DISCLOSURE OF THE INVENTION

In the first aspect, the present invention provides an optical information recording medium for recording information by a plurality of record mark lengths,
10 wherein the shortest mark length is at most 0.5 µm, and a crystal state is an unrecorded or erased state and an amorphous state is a recorded state, which has, on a substrate, at least a phase change recording layer, wherein erasing of information is made by
15 recrystallization which substantially proceeds by crystal growth from a boundary between a peripheral crystal portion and an amorphous portion or a melt portion.

In the second aspect, the present invention provides an optical information recording medium for recording
20 information by a plurality of record mark lengths, wherein the shortest mark length is at most 0.5 µm, and a crystal state is an unrecorded or erased state and an amorphous state is a recorded state, which has, on a substrate, a phase change recording layer which is made
25 of a thin film comprising Ge, Sb and Te as main components, wherein said medium will be crystallized when the recording layer is continuously irradiated at a

constant linear velocity with a recording laser beam having a writing power Pw sufficient to melt the recording layer, and an amorphous mark will be formed when the recording layer is irradiated at a constant

5 linear velocity with a recording laser beam having a writing power Pw sufficient to melt the recording layer, and then the recording laser beam is cut off.

In the third aspect, the present invention provides an optical information recording medium comprising a

10 substrate, and a first protective layer, a phase change recording layer, a second protective layer and a reflective layer, formed on the substrate sequentially from the incident direction of a recording or retrieving laser beam, for recording information by a plurality of

15 record mark lengths, wherein the shortest mark length is at most 0.5 μm, and a crystal state of the recording layer is an unrecorded or erased state and an amorphous state of the recording layer is a recorded state, wherein the phase change recording layer is made of a thin film

20 having a thickness of from 5 nm to 25 nm and comprising, as a main component, a GeSbTe alloy having a composition represented by a region (except for the boundary lines) defined by four linear lines, i.e. linear line A connecting $(Sb_{0.7}Te_{0.3})$ and Ge, linear line B connecting

25 $(Ge_{0.03}Sb_{0.68}Te_{0.29})$ and $(Sb_{0.95}Ge_{0.05})$, linear line C connecting $(Sb_{0.9}Ge_{0.1})$ and $(Te_{0.9}Ge_{0.1})$ and linear line D connecting $(Sb_{0.8}Te_{0.2})$ and Ge, in the GeSbTe ternary phase

diagram, and the second protective layer has a thickness
of from 5 nm to 30 nm.

In a further aspect, the present invention provides
an optical recording method which is preferably employed
5   when the above medium is used.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a view illustrating examples of
amorphous mark shapes.

Figure 2 is a view illustrating the change in
10   reflectance when recording was carried out on one
embodiment of the medium of the present invention.

Figure 3 is a GeSbTe ternary phase diagram showing
the compositional ranges for the recording layer of the
medium of the present invention.

15   Figures 4 are GeSbTe ternary phase diagrams showing
the compositional ranges of conventional GeSbTe
compositions.

Figures 5 are diagrammatical view illustrating an
example of the layer structures of media of the present
20   invention.

Figure 6 is a signal waveform diagram showing the
relation of the signal intensity with the amplitude and
modulation of a signal.

Figure 7 is a graph for illustrating the dependency
25   of the reflectance on the thickness of the first
protective layer.

Figure 8 is a view illustrating an embodiment of a

pulse-dividing method for the power three-valued modulation recording system.

Figure 9 is a diagrammatical view illustrating the change with time of the temperature of the recording layer.

Figure 10 is a graph showing an embodiment of a pulse-dividing method in the power three-valued modulation recording system suitable for mark length modulation recording.

Figure 11 is a schematic view illustrating the timing for the three types of gate-generating circuits to realize the pulse-dividing method in Figure 10.

Figures 12 are graphs showing the retrieving laser power dependency of jitter in Example 1 and Comparative Example 1.

Figures 13 are graphs showing the recording pulse-dividing method dependency of jitter in Example 1.

Figures 14 are graphs showing the recording pulse-dividing method dependency of jitter in Example 1.

Figures 15 are graphs showing the recording power dependency of jitter, reflectance and modulation in Example 2.

Figures 16 are graphs showing the repetitive overwriting number of times dependency of jitter, the reflectance and the modulation in Example 2.

Figures 17 are graphs showing the mark length dependency of jitter in Example 2(g1) and Example 2(d2).

Figures 18 are graphs showing the substrate tilt angle dependency of jitter in Example 2.

Figure 19 is a graph showing the α_1 and α_c dependency of jitter after ten times of overwriting in Example 4.

Figures 20 are graphs showing the repetitive overwriting number of times dependency of jitter, Rtop and the modulation in Example 4.

Figure 21(a) is a graph showing the pulse-dividing method dependency of jitter in Example 6, Figure 21(b) is a graph showing the writing power dependency of jitter, and Figure 21(c) is a graph showing the writing power dependency of the modulation and Rtop after ten times of overwriting.

Figures 22 are graphs showing the repetitive overwriting number of times dependency of jitter, Rtop and the modulation in Example 6.

Figure 23 is a graph showing the mark length dependency of jitter in Example 6.

Figure 24(a) is a graph showing the pulse-dividing method dependency of jitter in Comparative Example 2, Figure 24(b) is a graph showing the writing power dependency of jitter, and Figure 24(c) is a graph showing the writing power dependency of the modulation and Rtop after ten times of overwriting.

Figure 25 is a view illustrating the pulse-dividing method in the recording method employed in Comparative

Example 3.

Figures 26 are graphs showing the mark length dependency and the linear velocity dependency of jitter in Comparative Example 3.

Figures 27 are graphs showing the Pw and Pe dependency of jitter in Comparative Example 6.

Figure 28 is a graph showing the shortest mark length dependency of jitter in Example 8.

Figures 29 are graphs showing the Pw dependency of jitter in Example 10 and Comparative Example 8.

Figure 30 is a view illustrating the relation between the digital data signal and the wobble waveform.

Figure 31 is a view illustrating the mechanism for modulating the wobble waveform by a digital data signal.

Figures 32 are graphs showing the groove width dependency of the modulation and Rtop in Example 11.

DETAILED DESCRIPTION OF THE INVENTION

The present inventors have found that a high speed and high density stable recording can be made by using a phase change medium wherein a crystal state is an unrecorded or erased state and an amorphous state is a recorded state, and the erasing is carried out by recrystallization which substantially proceeds by crystal growth from the boundary between an amorphous portion or a melt portion and a peripheral crystal portion. Namely, by using such a medium, it is possible to conduct overwriting at a high speed, and conduct a high density

mark length modulation recording with a small jitter of a
mark edge, and the stability of the formed marks with the
lapse of time is excellent.

In general, the erasing step of amorphous marks is
5   caused by heating the recording layer up to a temperature
of at least the crystallization temperature and at most
the vicinity of the melting point to convert it to an
amorphous solid state or a melt state, and then cooling
for recrystallization.

10   According to the studies of the present inventors,
the following has been found. Namely, recrystallization
proceeds by two processes i.e. (1) formation of crystal
nuclei in an amorphous region and (2) crystal growth
starting from the boundary between an amorphous portion
15   or a melt portion and a crystal portion. The above-
mentioned effect can be obtained by suppressing the
former so that the crystal nuclei formation hardly
proceeds, and utilizing substantially only the latter
crystal growth process.

20   In usual, the crystallization proceeds at a
temperature of at least the crystallization temperature
and at most the vicinity of the melting point. However,
within this temperature range, the crystal nuclei
formation proceeds at a relatively low temperature side
25   and the crystal growth proceeds at a higher temperature
side. The crystal nuclei formation is not necessarily
required for the erasing. The erasing is possible when

the crystal growth proceeds at a high speed from, as a nucleus, the boundary point between the amorphous portion or melt portion and a peripheral crystal region surrounding it.

5   Particularly, the finer or shorter the mark is, the easier the crystallization is made instantaneously to the center of mark only by the crystal growth from the peripheral crystal portion, whereby the erasing can be made completely for an extremely short period of time. Accordingly, the effect is significant in a high density recording medium using fine marks with the shortest mark length of at most 0.5 μm, by which the erasing can be made at a level of at most 100 nsec and a high speed overwriting can be made.

15   In general, the high density recording can be made as the shortest mark length is short. However, the shortest mark length is preferably at most 10 nm in view of the stability of marks.

Further, as the width of mark is narrow, the crystallization tends to be made instantaneously to the center of mark only by the crystal growth from the peripheral crystal portion, such being preferred. Accordingly, it is preferred to adjust the track pitch of tracks on which the information is to be recorded to, for example, at most 0.8 μm so that the mark will not be broadened horizontally. In usual, the mark width is about a half of the track pitch. In general, as the

track pitch is narrow, a higher density recording can be made. However, the track pitch preferably at least 0.1 μm in view of the stability of mark. The track may be either a groove alone or both of a groove and a land.

5   The medium of the present invention is also different in the stability of an amorphous mark with the lapse of time.

Namely, within the temperature range of at least the crystallization temperature and at most the vicinity of

10   the melting point, the crystal growth from the peripheral crystal portion proceeds in a relatively high temperature region near the melting point and hardly proceeds at a low temperature, whereby the amorphous mark once formed is hardly crystallized and excellent in the stability

15   with the lapse of time. The crystallization temperature is usually within a range of from 100°C to 200°C, and the thermal stability can be maintained at such a temperature.

Particularly, in a usual use range of less than

20   100°C, the recorded amorphous mark is extremely stable, and the amplitude of recorded signals does not substantially deteriorate. On the contrary, it can be concluded from such stability with the lapse of time that the recording is accompanied by no substantial crystal

25   nuclei formation.

Further, it is another advantage of the medium of the present invention that in the mark length recording,

smooth mark edge of extremely low jitter can be formed.

In general, in the recording of amorphous marks, the recording layer is once melted and resolidified for conversion to an amorphous state. However, the
5 peripheral portion of the mark is of a relatively low temperature as compared with the center. Accordingly, in conventional media, recrystallization by the crystal nuclei growth is likely to cause in the peripheral portion of mark, by which coarse grains wherein amorphous
10 sections coexist and sway of mark edge is caused.

The erasing of the medium of the present invention is governed by the crystal growth from the boundary between the amorphous portion or melt portion and the crystal portion and it is made at a high speed. This
15 principle can be seen at a time of recording. Namely, similar principle will act at the time of recording, and the melt region is resolidified and converted to an amorphous state as well, only the crystal growth from the peripheral crystal portion is caused and the
20 crystallization by the crystal nuclei growth is hardly caused, whereby the mark edge hardly sways.

Namely, within the temperature range of at least the crystallization temperature and at most the vicinity of the melting point, the crystal growth from the peripheral
25 crystal portion proceeds only at a relatively high temperature region near the melting point and hardly proceeds at a low temperature. Accordingly, at the time

of this resolidification from the melt state, the boundary configuration of the amorphous mark is determined only by the cooling speed when the temperature decreases and passes the melting point.

5   And, coarse grains wherein amorphous sections due to the crystal nuclei growth at the time of resolidification coexist and which have been problematic in the prior art, is hardly formed in the periphery of amorphous mark. It is also found that this effect is extremely useful for

10   the suppression of noise due to the sway of mark edge.

Furthermore, the mark edge shape is stable and does not change with the lapse of time, whereby not only the initial jitter is small but also the jitter hardly deteriorates with the lapse of time.

15   The principle of the crystallization of the present invention will be described in further detail.

In the medium of the present invention, the boundary portion between the amorphous mark and the surrounding crystal portion becomes a nucleus for the crystal growth,

20   and no substantial crystal nuclei are formed in the interior of the amorphous mark. Accordingly, crystals grow solely from the boundary portion of the mark.

On the other hand, in a conventional $GeTe-Sb_2Te_3$ type recording layer, crystal nuclei are randomly formed in

25   the amorphous mark, and crystallization proceeds as they grow.

The difference between the two crystallization

processes can be confirmed by a transmission electron
microscope. When an erasing laser beam with a relatively
low power is applied direct-currently to both recording
layers after formation of amorphous marks, in the GeTe-
5   Sb_2Te_3 type recording layer, it is observed that
crystallization proceeds from the center of the amorphous
mark where the temperature becomes high, whereas in the
recording layer of the present invention, it is observed
that crystal grows from the periphery of the amorphous
10 mark. Particularly, the crystal growth from the front
end and the rear end is substantial.

The recording layer composition wherein erasing is
carried out by such principle is often seen in alloy
systems having excess Sb and other elements of up to
15 about 20 atomic% added to a composition in the vicinity
of a $Sb_{0.7}Te_{0.3}$ eutectic point, namely, a thin layer
comprising as a main component a $M_y(Sb_xTe_{1-x})_{1-y}$ alloy
wherein ($0.6 \leqq x \leqq 0.9$, $0 < y \leqq 0.2$ and M is at least one of
Ga, Zn, Ge, Sn, Si, Cu, Au, Al, Pd, Pt, Pb, Cr, Co, O, S,
20 Se, Ta, Nb and V).

An alloy having excess Sb contained in $Sb_{0.7}Te_{0.3}$ has
a characteristic that overwriting at a high linear
velocity is possible, since it shows extremely large
crystal growth from the crystal in a peripheral portion
25 of an amorphous mark as compared with a GeTe-Sb_2Te_3
pseudo binary alloy system. The excess Sb increases the
crystal growth speed from the peripheral crystal portion

to a great extent, not accelerates the random formation
and growth of crystal nuclei in the amorphous mark.

However, since a SbTe binary alloy shows not a
little the formation of crystal nuclei, the stability of
5 the amorphous mark with the lapse of time is remarkably
poor, whereby it is required to add proper elements.

According to the studies of the present inventors,
the addition of Ge is extremely effective for suppression
of the formation of crystal nuclei.

10 Now, whether or not recrystallization of the
amorphous mark is governed only substantially by
recrystallization from the peripheral crystal portion,
can be determined indirectly from the evaluation of the
stability with the lapse of time.

15 As a specific evaluation method, a method for
measuring the modulation of retrieving signals when
accelerated condition test under a high temperature high
humidity condition is carried out, may be mentioned.

Namely, when signals are recorded with a plurality
20 of mark length of which the shortest mark length is at
most 0.5 μm, the recording is made under the condition
satisfying the following relation:

$M_1/M_0 \geqq 0.9$

wherein M_0 represents a modulation of signals retrieved
25 immediately after the recording, and M_1 represents a
modulation of signals retrieved after the recording
medium is kept for 1000 hours under a condition of 80°C

and 80% relative humidity after the recording.

The mark length modulation system is not limited and, for example, EFM modulation, EFM plus modulation and (1,7)RLL-NRZI (run length limited-non return to zero inverted) modulation may be used. Random signals as shown in Figure 6 are recorded with the shortest mark length of at most 0.5 µm. For the above evaluation, it is preferred to set the shortest mark length at least about 0.2 µm. It should be mentioned that it is necessary to satisfy the above formula in one evaluation condition, and not necessary to satisfy the above formula in all the evaluation condition.

As an example, random signals of EFM plus modulation system are recorded with a plurality of mark lengths of which the shortest mark length is 0.4 µm.

The modulation is one obtained by standardizing a signal amplitude of the longest mark of this modulation system with the top signal intensity. Figure 6 shows the wave form of DC retrieving signals (retrieving signals including direct current component) when EFM plus modulated random signals are recorded and retrieved. The modulation is defined by a ratio I_{14}/I_{top} wherein I_{top} represents a signal intensity of a top of 14T mark and I_{14} is a signal amplitude.

If the modulation does not change, amorphous mark size can be determined to be sufficiently stable. If the modulation of random signals recorded before acceleration

test maintains at least 90% of the initial value even after the acceleration test, it can be presumed that the recording is accompanied with no substantial formation of crystal nuclei.

In the recording layer of the present invention, crystal growth from the peripheral crystal portion is likely to occur even in a high temperature region immediately below the melting point, and accordingly, crystal growth from the peripheral crystal portion may occur even when the recording layer is melted and resolidified in order to form an amorphous mark. Accordingly, in a case where the cooling rate after melting is so slow that it does not reach a critical cooling rate required for solidification as an amorphous substance, the entire melted region undergoes recrystallization almost instantaneously.

This can be confirmed by the following experiment.

On a polycarbonate substrate having a thickness of 0.6 mm and provided with a guide groove for a recording or retrieving laser beam, a $(ZnS)_{80}(SiO_2)_{20}$ first protective layer having a thickness of 68 nm, a $Ge_{0.05}Sb_{0.71}Te_{0.24}$ recording layer having a thickness of 18 nm, a $(ZnS)_{80}(SiO_2)_{20}$ second protective layer having a thickness of 20 nm and an $Al_{0.995}Ta_{0.005}$ reflective layer having a thickness of 250 nm, were formed in this order, and an ultraviolet-curable resin protective layer was further provided in a thickness of 4 μm. Two of such

laminates were bonded by a hot melt adhesive so that the recording layer sides were located inside, to obtain an optical recording medium. The composition of the recording layer was adjusted to be Sb/Te≒3 to make

5   overwriting at a linear velocity of at least 7 m/s possible. To this medium, an oval laser beam having a long diameter of about 100 µm and a short diameter of about 1.5 µm was applied for scanning in the short axis direction to carry out initialization by melting and

10   recrystallization.

A focused beam having a wavelength of 637 nm and NA=0.63, was applied for scanning along the guide groove at a linear velocity of 7 m/s, and a recording laser beam with a recording power Pw of 10 mW was applied direct-

15   currently, and then the power was rapidly downed to 1mW. Namely, the recording laser beam was substantially cut off. Here, the beam diameter was 0.9 µm, which corresponds to a region where the Gaussian beam energy intensity becomes at least $1/e^2$ of the peak intensity.

20   Figure 2 shows a change in reflectance before and after cutting off the recording laser beam. As shown in the lower side in Figure 2, the recording laser beam was cut off as the time passed. On the left side of the lower side in Figure 2, the recording laser beam is

25   continuously i.e. direct-currently applied, and on the right side, the laser beam is cut off. The same region was scanned with a retrieving laser beam having a

retrieving power of 1.0 mW, whereby the retrieving
waveform as shown in the upper part in Figure 2, was
obtained. This corresponds to the change in reflectance.

In the vicinity where the recording laser beam was
instantaneously cut off, the reflectance was low, and
before and after the cutting off of the recording laser
beam, the reflectance was substantially the same. As
observed by TEM, the portion at which the reflectance was
low, was amorphous, and the portions before and after
thereof were confirmed to be crystalline. Namely, so
long as the recording laser beam is continuously applied,
the melt portion will crystallize, and only the melt
region in the vicinity of the portion where the recording
laser beam was cut off, becomes to be amorphous.

Namely, when the recording laser beam is applied
continuously, the cooling rate of the recording layer
will be suppressed by the excess heat from the subsequent
portion, whereby a critical cooling rate required for the
formation of amorphous substance can not be obtained.
Whereas, if the recording laser beam is cut off once, the
excess heat from the subsequent portion is cut off,
whereby the cooling rate can be increased.

Further, when the recording power Pw was adjusted to
be at least 7 mW, an amorphous mark was formed by cutting
off the recording laser beam.

As a result of a study, it has been found that the
medium of the present invention generally undergoes

crystallization when continuously irradiated with a recording laser beam with a recording power P_w sufficient to melt the recording layer, at a constant linear velocity, and an amorphous mark is formed when

5 irradiation with a recording laser beam with a recording power P_w sufficient to melt the recording layer at a constant linear velocity, is followed by irradiation with a recording laser beam with a power of substantially zero. Here, a power of substantially zero means that the power

10 may not strictly be zero, and it is a bias power P_b represented by $0 \leq P_b \leq 0.2 P_w$, more preferably a bias power P_b represented by $0 \leq P_b \leq 0.1 P_w$.

In the present invention, recrystallization of the melt portion at the time of resolidification is almost

15 caused solely by the crystal growth from the peripheral solid phase crystal portion. Accordingly, the recrystallization portion is not formed at the central portion of the amorphous mark, whereby smooth and continuous mark edge is formed.

20 Heretofore, such a material which is remarkably crystallizable, has been considered to be unsuitable for a recording layer for mark length recording, because if a recording laser beam is applied for a long time to form a long mark, most of the melt region will be crystallized.

25 However, according to the study by the present inventors, in high density recording where the shortest mark length is less than 0.5 μm, good jitter is

obtainable by positively employing the competition
process between the conversion to amorphous state of the
melt region and the recrystallization from the boundary
of the peripheral solid phase crystal portion.

5   Thus, it has been found that as will be described
hereinafter, it is extremely effective to employ a pulse-
dividing system for the formation of a mark having a
length of nT, wherein a recording power Pw applied
section is combined with the power cutting off section
10   i.e. a bias power Pb applied section.

When recording is carried out by the pulse-dividing
system, as shown in Figure 1, herring bone-shaped (or
crescent-shaped) amorphous portions are linked to form an
amorphous mark.

15   The shape of the front end of the mark is determined
only by the shape of the front end of the front
herringbone-shaped amorphous portion, and the shape of
the rear end of the mark is determined by the shape of
the rear end of the last herringbone-shaped amorphous
20   portion.

Usually, the front end shape of an amorphous portion
is smooth, and accordingly, the front end shape of the
mark will also become smooth. Due to dissipation of the
heat forwardly, the cooling rate can be maintained to be
25   sufficiently high, whereby the shape reflects
substantially the shape of the forward end of the melt
region and accordingly governed by the rise time of the

recording pulse. The recording pulse i.e. the build-up in the Pw applied section, may be at most 2 or 3 nsec.

On the other hand, the rear end shape of an amorphous portion is determined by the cooling rate determined by the fall time of the recording pulse and the size of the recrystallized region progressing from the peripheral crystal portion, particularly the rear end crystal portion. To make the cooling rate sufficiently high, the fall time in the Pw applied section is preferably at most 2 or 3 nsec. The size of the recrystallized region can precisely be controlled by the length of off-pulse i.e. the Pb applied section.

Further, it is also important that the above-mentioned ultrarapid cooling structure is used as the layer structure, and the cooling rate of the recording layer is made as sharp as possible and at the same time, the spatial distribution of the cooling rate is adjusted to be sharp in the vicinity of the rear end of the mark, so that the position of the end of the mark will not sway.

Now, the present inventors have extensively studied the optical recording medium by which a short mark can be recorded at a high speed and which is excellent in the stability of the recording mark with the lapse of time, and as a result, found that a specific composition having Ge added in the vicinity of a $Sb_{0.7}Te_{0.3}$ eutectic composition is particularly excellent, and obtained an optical recording medium excellent in other properties by

choosing an appropriate layer structure.

Namely, the present inventors have paid an attention to a new ternary alloy having excessive Sb and Ge added to $Sb_{0.7}Te_{0.3}$ and studied its applicability to high density mark length modulation recording. As a result, it has been found that a medium employing a recording layer composition having an extremely limited Ge-Sb-Te ratio, defined by the four linear lines A, B, C and D in the GeSbTe ternary phase diagram as shown in Figure 3, is excellent in the repetitive overwriting durability and the stability with time in high density mark length modulation recording.

Namely, the recording layer is made of a thin film comprising, as a main component, a GeSbTe alloy having a composition represented by a region (except for the boundary lines) defined by four linear lines, i.e. linear line A connecting $(Sb_{0.7}Te_{0.3})$ and Ge, linear line B connecting $(Ge_{0.03}Sb_{0.68}Te_{0.29})$ and $(Sb_{0.95}Ge_{0.05})$, linear line C connecting $(Sb_{0.9}Ge_{0.1})$ and $(Te_{0.9}Ge_{0.1})$ and linear line D connecting $(Sb_{0.8}Te_{0.2})$ and Ge, in the GeSbTe ternary phase diagram. This recording layer is employed in combination with the layer structure as described hereinafter to make a medium which is very useful for high density mark length modulation recording with the shortest mark length of at most 0.5 μm. And, it is possible to obtain a recording density equal to DVD and excellent retrieving interchangeability with DVD.

It is also possible to secure a repetitive overwriting durability and a wide margin wherein excellent jitter can be obtained for the change in the recording power and retrieving power.

5   Within this compositional range, as the amount of Sb is larger than $y=0.7$ in the Sb_yTe_{1-y} alloy, the excess Sb amount increases, whereby the crystallization speed becomes high, and it becomes possible to overwrite at a high speed.

10   More specifically, in the EFM plus modulation recording (mark length modulation recording of 8-16 modulation), even if the length of 3T mark as the shortest mark is shortened to a level of 0.4 μm or 0.35 μm, good jitter is obtainable. Further, an servo signal 15 can be obtained, and tracking servo can be applied by a conventional read-only DVD drive. Further, overwriting is possible at a linear velocity within a range of from 1 to 10 m/s.

    Thus, it is possible to obtain rewritable DVD having 20 the same capacity as read-only DVD and substantial retrieving interchangeability.

    If the excess Sb amount is controlled, the high density overwriting of high quality as described above, can be accomplished at a high linear velocity of at least 25 8 m/s. Further, by changing the recording pulse dividing method (the pulse strategy) depending upon the linear velocity as described hereinafter, good overwriting

becomes possible within a wide linear velocity range including at least from 3 to 8 m/s.

This composition will be described in further detail.

With a composition in the neighborhood of $Sb_{0.7}Te_{0.3}$

5   eutectic point wherein the amount of Ge added is at most 10 atomic %, the crystallization speed tends to increase as the Sb/Te ratio increases. Namely, Sb in excess of $Sb_{0.7}Te_{0.3}$ will precipitate as Sb clusters which serve as crystal nuclei in the process of recrystallization. And,

10   in the absence of Sb in excess of $Sb_{0.7}Te_{0.3}$, erasing performance becomes insufficient, whereby overwriting is substantially impossible. Further, at the time of initialization, there will be no substantial formation of nuclei, whereby there is a problem that the

15   initialization is difficult, and the productivity is very poor (linear line A).

On the other hand, if the amount of Sb is increased in the $Sb_{0.7}Te_{0.3}$ eutectic binary alloy, the crystallization temperature decreases, and the stability

20   with time of amorphous marks tends to be impaired, although the crystallization speed increases. Further, such is not suitable for recording at a low linear velocity of about 3 m/s, and formed amorphous marks will disappear when irradiated with a retrieving laser beam

25   (with a laser power of about 1 mW) in a short period of time. Accordingly, Sb in excess of linear line D connecting $(Sb_{0.8}Te_{0.2})$ and Ge should not be contained.

Further, within the range for the excess amount of Sb as defined by linear lines A and D, with the SbTe binary system by itself, the crystallization temperature is low, and crystal nuclei of excess Sb will be present,

5 whereby amorphous marks tend to be too unstable. Therefore, as the excess Sb amount is large, added amount of Ge is larger. By four coordinate bonding of Ge, the crystal nuclei growth rate can be controlled substantially completely. As a result, the

10 crystallization temperature increases, and archival life increases. Linear line B connecting ($Ge_{0.03}Sb_{0.68}Te_{0.29}$) and ($Sb_{0.95}Ge_{0.05}$) defines this condition. More preferably, Ge is contained in an amount larger than the linear line B' connecting ($Ge_{0.03}Sb_{0.68}Te_{0.29}$) and ($Sb_{0.9}Ge_{0.1}$).

15 Further, if the Ge content becomes 10 atomic % or higher, jitter deteriorates during mark length recording, and a high melting point Ge compound, particularly GeTe, tends to segregate by repetitive overwriting. Further, it is undesirable that crystallization of an amorphous

20 film immediately after film formation, tends to be very difficult (linear line C). To reduce jitter, Ge is more preferably at most 7.5 atomic %.

To carry out overwriting at a linear velocity of at least 3 m/s, the recording layer is preferably made of a

25 thin film comprising, as a main component, a $Ge_x(Sb_yTe_{1-y})_{1-x}$ alloy ($0.04 \leqq x < 0.10$, $0.72 \leqq y < 0.8$). Namely, for recording at a linear velocity of at least 3 m/s, it

is preferred that the Sb amount is increased so that in the Sb_yTe_{1-y} alloy, $y \geqq 0.72$. However, by increasing the Sb amount, stability of amorphous marks tends to slightly deteriorate, and to supplement this, it is preferred to

5 adjust Ge to be slightly large at a level of $x \geqq 0.04$.

Further, to carry out overwriting at a linear velocity of at least 7 m/s, the recording layer is preferably made of a thin film comprising, as a main component, a $Ge_x(Sb_yTe_{1-y})_{1-x}$ alloy ($0.045 \leqq x \leqq 0.075$, $0.74 \leqq$

10 $y < 0.8$). Namely, for recording at a linear velocity of at least 7 m/s, it is preferred that the Sb amount is further increased so that in the Sb_yTe_{1-y} alloy, $y \geqq 0.74$. Here, in order to increase the stability of amorphous marks, the amount of Ge is adjusted to be $x \geqq 0.045$. On

15 the other hand, at a high linear velocity, jitter is likely to deteriorate, and to supplement this, the amount of Ge is adjusted to be $x \leqq 0.075$.

There have been some reports on a GeSbTe ternary composition or a recording layer composition comprising

20 such a ternary composition as the base material and additional elements (JP-A-61-258787, JP-A-62-53886, JP-A-62-152786, JP-A-1-63195, JP-A-1-211249, and JP-A-1-277338).

However, the compositions disclosed in these

25 publications are all poorer in Sb than linear line A connecting ($Sb_{0.7}Te_{0.3}$) and Ge and different from the compositional range of the present invention.

These compositions contain as the main component a Sb_2Te_3 metal compound composition. Further, with a GeTe-Sb_2Te_3 pseudo binary alloy system, excess Sb has an effect to slow down the crystallization speed, as

5 contrary to the present invention. Accordingly, to carry out overwriting at a high linear velocity of at least 5 m/s, it is rather detrimental to incorporate excess Sb to a composition on the linear line of GeTe-Sb_2Te_3, particularly to the $Ge_2Sb_2Te_5$ composition.

10 As compositions having a third element including Ge selectively added to the composition in the neighborhood of $Sb_{0.7}Te_{0.3}$ containing excess Sb, there are those disclosed in JP-A-1-100745 (compositional range α in Figure 4 (a)) and JP-A-1-303643 (compositional range β

15 in Figure 4 (a)).

However, in JP-A-1-100745, the base composition has an extremely wide range such that in $Sb_{1-x}Te_x$, $0.10 \leqq x \leqq 0.80$. Accordingly, the concept of the present invention that only a region where Sb is in excess of $Sb_{0.7}Te_{0.3}$ is

20 utilized to attain excellent repetitive overwriting durability and archival life in high density recording, is not disclosed or suggested.

In JP-A-1-303643, no mention is made about a problem that in high density recording as in the present

25 invention, if Sb is contained excessively beyond linear line D, stability with time of amorphous marks will be impaired. Further, neither publication mentions about

the problem resulting from the excess content of Ge
beyond linear line C.

Further, as compositions which partially overlap
with the recording layer composition of the present
invention, there are those disclosed in JP-A-1-115685
(compositional range γ), JP-A-1-251342 (compositional
range δ), JP-A-3-71887 (compositional range ϵ) and JP-A-
4-28587 (compositional range η), as shown in Figure 4
(b).

JP-A-1-115685 discloses a composition having Au, Pd
added to a base material of compositional range γ, but
it is intended for low density recording and is
substantially distinguished from the composition of the
present invention by linear lines A and B. The
composition in that publication is one suitable for
recording at a low density corresponding to a mark length
of about 1.1 µm (linear velocity: 4 m/s, frequency: 1.75
MHz, square wave with a duty of 50%) and for DC erasing,
and it is considered to be different in the suitability
of the composition from the composition of the present
invention intended for high density recording including
short marks.

The compositional range δ disclosed in JP-A-1-251342
is an extremely Ge-rich GeSbTe system consisting
essentially of a system having at least about 10 atomic %
of Ge added to a $Sb_{0.7}Te_{0.3}$ eutectic crystal, and is
substantially distinguished from the composition of the

present invention by linear line C. Within the compositional range δ, a composition containing more than 10 atomic % of Ge, has a serious problem that, as mentioned above, the crystallization speed is slow, and

5 particularly, initialization to crystallize the recording layer after the film formation, is difficult, whereby the productivity is low and can not be practically employed. In this publication, in order to overcome the problem of this crystallization speed, Au or Pd which forms crystal

10 nuclei, is added. However, in a region where Ge is smaller than linear line C as in the present invention, such an addition is not required.

Further, in the publication, it is described that if the amount of Ge is less than 10 atomic %, no adequate

15 change in light intensity as between a recorded portion and a non-recorded portion, is obtainable. Whereas, in the present invention, by adjusting the layer structure including the protective layer and the reflective layer, a very large change in light intensity at a level of a

20 modulation of at least 60%, is obtained.

The compositional range ε disclosed in JP-A-3-71887 is intended for low density recording, and is substantially distinguished from the composition of the present invention by linear line C. Especially, the

25 concept of the present invention that the compositional range of the present invention is utilized to obtain excellent repetitive overwriting durability and archival

life in high density recording, is not disclosed or suggested.

The compositional range η disclosed in JP-A-4-28587 includes extremely Sb-rich and Ge-rich compositions, and is substantially distinguished from the composition of the present invention by linear line D.

As described in the foregoing, none of the publications discloses the technical problem relating to high density mark length modulation recording where the shortest mark length is 0.5 μm, as intended to be solved by the present invention, or selection of the optimum composition or improvement of the layer structure or the recording method to solve such a problem.

Now, the layer structure of the optical information recording medium of the present invention will be described. The medium of the present invention makes it possible to realize a medium which is capable of overwriting within a wide linear velocity range covering from at least 3 m/s to 8 m/s, preferably from 1 m/s to 10 m/s in high density mark length modulation recording where the shortest mark length is at most 0.5 μm, by the combination of the recording layer having the above described composition with the layer structure as described hereinafter. And, it is thereby possible to maintain so-called retrieving interchangeability with DVD.

The phase-change recording layer is covered with the upper and lower protective layers.

Further, as shown in Figure 5 (a), the medium of the present invention has a structure of substrate 1/first protective layer 2/recording layer 3/second protective layer 4/reflective layer 5, and the top thereof is coated

5   with an ultraviolet curable or thermosetting resin (protective coating layer 6). The order of the respective layers as shown in Figure 5 (a) is suitable when a focused laser beam for recording and retrieving is irradiated to the recording layer through the transparent

10 substrate.

Otherwise, the medium may take a structure in which the above order of the respective layers is reversed so that they are laminated in the order of substrate 1/reflective layer 5/second protective layer 4/recording

15 layer 3/first protective layer 2, as shown in Figure 5 (b). This layer structure is suitable when the focused laser beam is applied from the first protective layer side. Such a structure is useful in a case where the object numerical aperture NA is at least 0.7, so that the

20 necessity for shortening the distance between the recording layer and the object lens is high.

With the structure shown in Figure 5 (a), the substrate may be made of a transparent resin such as a polycarbonate, acrylic or polyolefin resin, or a

25 transparent glass may be employed as the substrate.

Among them, a polycarbonate resin is most widely employed for CD and is inexpensive, and thus is most

preferred.

Also with the structure shown in Figure 5 (b), a
resin or glass may be employed, but the substrate itself
is not required to be transparent, and there may be a
5   case where it is preferred to employ glass or an aluminum
alloy in order to increase the rigidity or flatness.

On the substrate, a groove with a pitch of at most
0.8 µm is formed to guide the recording or retrieving
laser beam. However, this groove may not necessarily be
10 a geometrically trapezoidal groove, and it may be a
groove formed optically, for example, by forming a
waveguide having different reflective indices, for
example, by ion injection.

In the layer structure disclosed in Figure 5 (a), in
15 order to prevent deformation by a high temperature at the
time of recording, a first protective layer 2 is formed
on the substrate surface, and a second protective layer 4
is formed on the recording layer 3. The second
protective layer 4 has a plurality of functions i.e. to
20 prevent mutual diffusion of the recording layer 3 and the
reflective layer 5 and to effectively release the heat to
the reflective layer 5 while suppressing deformation of
the recording layer.

Also in Figure 5 (b), as observed from the incident
25 side of the focused laser beam, the second protective
layer 4 has functions to prevent mutual diffusion between
the recording layer 3 and the reflective layer 5, to

release the heat and to prevent deformation of the recording layer. The first protective layer in the Figure 5 (b) has functions to prevent deformation of the recording layer, to prevent direct contact of the recording layer with air (to prevent oxidation or contamination) and to prevent damages of the recording layer due to contact with an optical pickup.

A protective layer may further be provided between the reflective layer and the substrate, by which, for example, thermal damages to a resin substrate can be prevented.

With the structure disclosed in Figure 5 (b), it is preferred to further provide, outside the first protective layer 2, a harder dielectric or amorphous carbon protective layer or an ultraviolet curable or thermosetting resin layer. Otherwise, it is also possible to bond a thin transparent sheet having a thickness of from 0.05 to 0.6 mm so that the focused laser beam may be applied through this thin sheet.

Further, a medium such as DVD takes a structure wherein media of Figure 5 (a) are bonded by an adhesive with the recording layer sides located inside. With the media of Figure 5 (b), they are bonded reversely with the recording layer sides located outside. Further, with the medium of Figure 5 (b), tracking grooves may be formed on both sides of one substrate by injection molding, and multi layers may be formed on both sides by sputtering.

The recording layer 3, the protective layers 2 and 4 and the reflective layer 5 are formed by e.g. sputtering.

With a view to preventing oxidation or contamination among the respective layers, it is preferred to carry out film forming by an in-line apparatus having a target for the recording layer, a target for the protective layers and, if necessary, a target for the reflective layer set in the same vacuum chamber.

The material for the protective layers 2 and 4 is determined taking into consideration the refractive index, the thermal conductivity, the chemical stability, the mechanical strength, the adhesive property, etc. Usually, an oxide, sulfide, nitride or carbide of a metal or semiconductor, or a fluoride of e.g. Ca, Mg or Li, which is highly transparent and has a high melting point, can be employed.

Such an oxide, sulfide, nitride, carbide or fluoride may not necessarily take a stoichiometrical composition, and in order to control the refractive index, etc., it is effective to control the composition or to use them as a mixture.

In the protective layers 2 and 4, the compositional ratio and the mixing ratio may change in the thickness direction. Further, the protective layers 2 and 4 may comprise a plurality of layers, respectively. Respective layers thereof may be different in the compositional ratio and mixing ratio depending upon the characteristics

to be required.

Taking into consideration the repetitive recording characteristics, the film density of these protective layers is preferably at least 80% of the bulk state from the viewpoint of the mechanical strength. In the case of employing a thin film of a mixed dielectric, the following theoretical density may be used as the bulk density.

$$\rho = \sum m_i \rho_i \qquad (1)$$

m_i : mol concentration of each component i

ρ_i : bulk density of each component

The recording layer 3 of the medium of the present invention is a phase change recording layer, and its thickness is usually preferably within a range of from 5 nm to 100 nm.

If the thickness of the recording layer 3 is thinner than 5 nm, it tends to be difficult to obtain adequate contrast, and the crystallization speed tends to be slow, and erasing of the record in a short period of time tends to be difficult.

On the other hand, if it exceeds 100 nm, it tends to be difficult to obtain optical contrast, and cracking is likely to occur, such being undesirable.

Further, in high density recording where it is required to obtain high contrast so as to be interchangeable with a read-only ROM disk such as DVD and the shortest mark length is at most 0.5 μm, the thickness

of the recording layer is preferably from 5 nm to 25 nm.
If the thickness is less than 5 nm, the reflectance tends
to be too low, and an influence of a non-uniform
composition at the initial stage of the film formation or
5   a rough film, tends to appear, such being undesirable.

On the other hand, if it is thicker than 25 nm, the
heat capacity tends to be large, whereby the recording
sensitivity tends to be poor, and the crystal growth
tends to be three dimensional, whereby edges of amorphous
10   marks tend to be non-uniform, thus leading to an increase
of jitter. Further, the volume change due to the phase
change of the recording layer tends to be distinct,
whereby the repetitive overwriting durability tends to be
poor, such being undesirable. From the viewpoint of the
15   jitter of the mark edges and the overwriting durability,
the thickness is more preferably at most 20 nm.

Further, the density of the recording layer is
preferably at least 80%, more preferably at least 90%, of
the bulk density. Here, the bulk density may, of course,
20   be actually measured by preparing an alloy block, but an
approximate value can be obtained by replacing the molar
concentrations of the respective components in the above
Formula (1) with atomic % of the respective elements and
by replacing the bulk densities with the molecular
25   weights of the respective elements.

For the density of the recording layer, in a
sputtering method, it is necessary to increase the amount

of high energy Ar irradiated to the recording layer, for example, by lowering the pressure of the sputtering gas (rare gas such as Ar) during the film forming, or by disposing the substrate closely in front of the target.

5　The high energy Ar is one wherein a part of Ar ions irradiated to the target for sputtering, is rebound to reach the substrate side, or one wherein Ar ions in the plasma are accelerated by the sheath voltage over the entire surface of the substrate to reach the substrate.

10　　The irradiation effect of such a high energy rare gas is called an atomic peening effect. In sputtering with Ar gas which is commonly used, Ar will be included in the sputtered film by such an atomic peening effect. The atomic peening effect can be estimated from the

15　amount of Ar in the film. Namely, the amount of Ar being small, means that the irradiation effect of high energy Ar is small, whereby a film of a low density is likely to be formed. On the other hand, if the amount of Ar is large, irradiation of high energy Ar is vigorous, and

20　although the density becomes high, Ar included in the film will precipitate as void during repetitive overwriting, whereby the repetitive overwriting durability tends to be low. A proper amount of Ar in the recording layer film is from 0.1 atomic % to 1.5 atomic %.

25　Further, it is advisable to employ high frequency sputtering rather than direct current sputtering, since a high density film can be obtained while reducing the

amount of Ar in the film.

In the present invention, the recording layer is made of a thin film comprising, as a main component, a GeSnTe alloy having the above described composition. Namely, the ratio in amount of the respective elements of Ge, Sb and Te in the recording layer may be in the above described compositional range, and other elements may further be incorporated to the recording layer in a total amount of about 10 atomic %.

Further, the optical constant of the recording medium may be finely adjusted by adding from 0.1 atomic % to 5 atomic % of at least one element selected from O, N and S to the recording layer. However, it is not desirable to add such an element beyond 5 atomic %, since the crystallization speed will thereby be decreased, whereby the erasing performance deteriorates.

Further, in order to increase the stability with time without lowering the crystallization speed at the time of overwriting, at least one member selected from the group consisting of V, Nb, Ta, Cr, Co, Pt and Zr is preferably added in an amount of at most 8 atomic %. More preferably, such a member is added in an amount of from 0.1 atomic % to 5 atomic %. The total amount of such additive elements and Ge is preferably at most 15 atomic %, relative to SbTe. If they are contained excessively, phase separation other than Sb is likely to take place. Particularly, when the content of Ge is at

least 3 atomic % and at most 5 atomic %, the effect of
the addition is substantial.

It is preferred to add at least one member of Si, Sn
and Pb in an amount of at most 5 atomic %, in order to
improve the archival life and to finely adjust the
refractive index. The total content of these additive
elements and Ge, is preferably at most 15 atomic %.
These elements have the same four coordinate networks as
Ge.

Addition of Al, Ga and/or In in an amount of at most
8 atomic % is effective to increase the crystallization
temperature and at the same time to reduce jitter or to
improve the recording sensitivity. However, segregation
is also likely to result, it is preferred to adjust the
amount to at most 6 atomic %. Further, the total content
of such elements and Ge is preferably at most 15 atomic %,
more preferably at most 13 atomic %.

Addition of Ag in an amount of at most 8 atomic % is
also effective to improve the recording sensitivity, and
especially when this is employed in the case where the
amount of Ge exceeds 5 atomic %, the effect is remarkable.
However, the addition exceeding 8 atomic % is not
desirable, since jitter will increase, or the stability
of amorphous marks tends to be impaired. If the total
amount of Ag and Ge exceeds 15 atomic %, segregation is
likely to result, such being undesirable. The content of
Ag is most preferably at most 5 atomic %.

The recording layer 3 of the recording medium of the present invention is usually amorphous in the state after film formation. Accordingly, it is necessary to crystallize the entire surface of the recording layer

5   after the film formation to change it to an initialized state (unrecorded state).

As an initialization method, in the case of an alloy containing excess Sb in $Sb_{0.7}Te_{0.3}$, initialization may be carried out by annealing in a solid phase. However, in

10   the case of a composition which further contains Ge, it is preferred to initialize it by melt recrystallization wherein the recording layer is once melted and then crystallized by gradually cooling for resolidification.

The recording layer of the present invention

15   contains no substantial nuclei formed by crystal growth immediately after the film formation, whereby crystallization in a solid phase is difficult, but by the melt recrystallization, a few crystal nuclei will be formed and then melted, and recrystallization is

20   accelerated at a high speed mainly by the crystal growth.

Further, crystals formed by the melt recrystallization and crystals formed by annealing in the solid phase, are different in reflectance, and if they are present in a mixed state, they may cause a noise.

25   And, at the time of actual overwrite recording, the erased portion will be crystals formed by the melt recrystallization, and accordingly, the initialization is

also preferably carried out by the melt recrystallization.

Here, melting of the recording layer is limited locally and in a short time of at most about 1 msec.   If the melt region is broad, or the melting time or cooling time is long, the respective layers may be damaged, or the surface of a plastic substrate may be deformed, by the heat.

To provide such a heat history, a high power semiconductor laser beam with a wavelength of from about 600 to 1,000 nm is irradiated as focused to have a long axis of from 100 to 300 µm and a short axis of from 1 to 3 µm and scanned at a linear velocity of from 1 to 10 m/s so that the short axis direction is the scanning axis. Even with a similarly focused laser beam, if it is close to a circular shape, the melt region tends to be too broad, whereby reconversion to amorphous state is likely to take place and damage to the multi layer structure or to the substrate tends to be large, such being undesirable.

The fact that the initialization has been carried out by the melt recrystallization, can be confirmed as follows.   Namely, to the medium after the initialization, a recording laser beam with a recording power Pw sufficient to melt the recording layer, having a spot with a diameter smaller than about 1.5 µm, is applied direct-currently at a constant linear velocity.   In a case where a guide groove is present, this operation is

carried out in a state where a tracking servo and a focus servo are applied to a track consisting of a groove or a land.

Thereafter, on the same track, an erasing laser beam
5 with an erasing power Pe ($\leqq$Pw) is applied direct-currently, and if the reflectance of the erased state thereby obtained, is substantially the same as the reflectance of the totally unrecorded initial state, the initialized state is confirmed to be the melt re-
10 crystallized state.

Namely, the recording layer was once melted by irradiation with the recording laser beam, and the state where it was completely re-crystallized by irradiation with the erasing laser beam, is in the melt-re-
15 crystallized state, as passed through the processes of melting by the recording laser beam and recrystallization by the erasing laser beam.

Here, the reflectance R_{ini} in the initialized state being substantially the same as the reflectance R_{cry} in
20 the melt-re-crystallized state, means that the difference in reflectance between the two as defined by (R_{ini}-R_{cry})/{(R_{ini}+R_{cry})/2}, is at most 20%. Usually, merely by the solid phase crystallization such as annealing, the difference in the reflectance is larger than 20%.

25 Now, layers other than the recording layer will be described.

The layer structure of the present invention belongs

to one type of layer structure so-called a rapid cooling structure. In the rapid cooling structure, a layer structure is employed whereby the heat dissipation is prompted to increase the cooling rate at the time of
5 resolidification of the recording layer, whereby a high erasing ratio by a high speed crystallization will be realized while avoiding the problem of recrystallization at the time of amorphous mark formation. For this purpose, the thickness of the second protective layer is
10 adjusted to be at least 5 nm and at most 30 nm. If the thickness is thinner than 5 nm, the structure is likely to break due to e.g. deformation during the melting of the recording layer, or the heat dissipation effect tends to be so large that the power required for recording
15 tends to be unnecessarily large.

The thickness of the second protective layer in the ultrarapid cooling structure of the present invention, is substantially influential over the durability in repetitive overwriting, and it is important also with a
20 view to preventing deterioration of jitter. If the thickness exceeds 30 nm, the temperature difference between the recording layer side and the reflective layer side of the second protective layer becomes large at the time of recording, and due to the difference in the
25 thermal expansion at both sides of the protective layer, the protective layer itself tends to deform asymmetrically. Repetition of this deformation brings

about accumulation of microscopic plastic deformation in the interior of the protective layer, thus leading to an increase of noise, such being undesirable.

By using the recording layer of the present invention, low jitter can be realized in high density recording with the shortest mark length of at most 0.5 μm. However, according to the study by the present inventors, in order to realize high density recording, in a case where a laser diode with a short wavelength (such as a wavelength of at most 700 nm) is employed, it will be required to take a due care also with respect to the layer structure of the above-mentioned rapid cooling structure. Especially, in the study of one beam overwrite characteristics employing a focused laser beam having a wavelength of at most 500 nm and a numerical aperture NA at a level of at least 0.55, it has been found important to make the temperature distribution in the mark width direction to be flat in order to obtain a high erasing ratio and a wide erasing power margin. This is also true in an optical system corresponding to DVD wherein an optical system having a wavelength of from 630 to 680 nm and NA=0.6 is employed. In high density mark length modulation recording employing such an optical system, a material having a particularly low thermal conductivity is used as the second protective layer. Preferably, the film thickness is adjusted to be from 10 nm to 25 nm.

In either case, the erasing ratio and the erasing power margin can be improved by employing a material having a particularly high thermal conductivity for the reflective layer 5 formed thereon.

5   According to the study by the present inventors, in order to let the recording layer of the present invention perform particularly good erasing characteristics in a wide erasing power range, it is preferred to employ a layer structure whereby not only the temperature

10   distribution or the change with time in the film thickness direction, but also the temperature distribution in the film plane direction (a direction perpendicular to the recording beam scanning direction) is made to be flat as far as possible.

15   The present inventors have tried to broaden the range for recrystallization and to increase the erasing ratio and the erasing power margin without melting and reconversion to amorphous state, by flattening the temperature distribution in the transverse direction of

20   the track in the medium by properly designing the layer structure of the medium.

On the other hand, it has been found that by promoting heat dissipation from the recording layer to the reflective layer having an extremely high thermal

25   conductivity via a very thin second protective layer having a low thermal conductivity, the temperature distribution in the recording layer becomes flat. Even

if the thermal conductivity of the second protective
layer is made high, the heat dissipation effect can be
accelerated, but if the heat dissipation is accelerated
too much, the irradiation power required for recording
5   will be high, i.e. the recording sensitivity will
remarkably be low.

In the present invention, it is preferred to employ
a thin second protective layer having a low thermal
conductivity.

10 By using a thin second protective layer having a low
thermal conductivity, the thermal conduction from the
recording layer to the reflective layer will be delayed
for a few nsec to a few tens nsec at the initiation of
the recording power irradiation, and thereafter, heat
15 dissipation to the reflective layer can be promoted,
whereby it is possible to avoid lowering the recording
sensitivity unnecessarily by heat dissipation.

A conventional material for the protective layer
containing, as the main component, SiO_2, Ta_2O_5, Al_2O_3, AlN,
20 SiN or the like, is not preferred for the second
protective layer 4 of the medium of the present invention,
since the thermal conductivity of the material itself is
too high. Namely, the thermal conductivity of a metal
oxide or nitride is higher by at least one figure as
25 compared with the after-mentioned protective layer to be
used for the protective layer of the present invention,
even when compared with the same thin film state.

On the other hand, heat dissipation in the reflective layer can be accomplished even by increasing the thickness of the reflective layer. However, if the thickness of the reflective layer exceeds 300 nm, the

5   thermal conduction in the film thickness direction rather than the in-plane direction of the recording layer, becomes remarkable, whereby the effect for improving the temperature distribution in the in-plane direction can not be obtained. Further, the heat capacity of the

10 reflective layer itself will increase, and it tends to take time for cooing of the reflective layer, and consequently of the recording layer, whereby formation of amorphous marks will be hindered. It is most preferred that a reflective layer having a high thermal

15 conductivity is formed to be thin so that heat dissipation in the transverse direction is selectively promoted.

The conventional rapid cooling structure is intended to release the heat from the recording layer to the

20 reflective layer as quickly as possible, paying an attention only to one-dimensional heat dissipation in the thickness direction, and no adequate attention has been paid to the flattening of the temperature distribution in the in-plane direction.

25 The "ultra rapid cooling structure taking into consideration the effect for delaying the thermal conduction by the second protective layer" according to

the present invention, is more effective when applied to
the recording layer of the present invention, as compared
with the application to the conventional GeTe-Sb_2Te_3
recording layer, because with the recording layer of the
5 present invention, the crystal growth at the time of
resolidification in the vicinity of Tm is a rate
controlling factor for the recrystallization. To
maximize the cooling rate in the vicinity of Tm to ensure
and secure formation of amorphous marks and their edges,
10 the ultra rapid cooling structure is effective, and while
high speed erasing intrinsically possible in the vicinity
of Tm, by flattening of the temperature distribution in
the in-plane direction, erasing by recrystallization can
be secured to a higher erasing power level.

15   In the present invention, the material for the
second protective layer preferably has a low thermal
conductivity, and the index for the low thermal
conductivity is 1×10^{-3} pJ/(μm·K·nsec). However, it is
difficult to directly measure the thermal conductivity in
20 a thin film state of such a low thermal conductivity
material, and instead, an index may be obtained from a
thermal simulation and the results of actual measurement
of the recording sensitivity.

   As a material for the second protective layer having
25 a low thermal conductivity which brings about preferred
results, a composite dielectric is preferred which
contains from 50 mol% to 90 mol% of at least one member

selected from the group consisting of ZnS, ZnO, TaS$_2$ and
rare earth sulfides and which further contains a heat
resistant compound having a melting point or a
decomposition point of at least 1,000°C.

5   More specifically, a composite dielectric is
preferred which contains from 60 mol% to 90 mol% of a
sulfide of a rare earth element such as La, Ce, Nd or Y.

Otherwise, it is preferred that the compositional
range of ZnS, ZnO or a rare earth sulfide is made to be
10   from 70 to 90 mol%.

As the heat resistant compound having a melting
point or a decomposition point of at least 1,000°C, to be
mixed therewith, an oxide, nitride or carbide of e.g. Mg,
Ca, Sr, Y, La, Ce, Ho, Er, Yb, Ti, Zr, Hf, V, Nb, Ta, Zn,
15   Al, Si, Ge or Pb, or a fluoride of e.g. Ca, Mg or Li, may
be employed.

Particularly, as a material to be mixed with ZnO, a
sulfide of a rare earth element such as Y, La, Ce or Nd,
or a mixture of a sulfide and an oxide, is preferred.

20   The thickness of this second protective layer is at
most 30 nm, preferably at most 25 nm. If the thickness
exceeds 30 nm, no adequate effect for flattening the
temperature distribution in the mark width direction can
be obtained. If the thickness is less than 5 nm, the
25   effect for delaying the thermal conductivity at the
second protective layer portion tends to be insufficient,
whereby the decrease in the recording sensitivity tends

to be remarkable, such being undesirable.

The thickness of the second protective layer 4 is preferably from 15 nm to 25 nm when the wavelength of the recording laser beam is from 600 to 700 nm, and it is preferably from 5 to 20 nm, more preferably from 5 to 15 nm, when the wavelength is from 350 to 600 nm.

In the present invention, a thin reflective layer 5 of at most 300 nm having a very high thermal conductivity, is employed to promote the heat dissipation effect in the transverse direction.

In general, the thermal conductivity of a thin film differs substantially from the thermal conductivity in the bulk state and is usually smaller. Particularly, with a thin film of less than 40 nm, by the influence of the scattered structure at the initial stage of the growth, the thermal conductivity may sometimes be smaller by at least one figure, such being undesirable. Further, depending upon the film forming conditions, the crystallizability or the amount of impurities may differ, which will be a factor for various thermal conductivities even with the same composition.

In the present invention, to define the reflective layer having a high thermal conductivity which shows good characteristics, the thermal conductivity of the reflective layer can be directly measured, but the degree of the thermal conductivity can be estimated by means of the electric resistance. With a material like a metal

film whereby electrons govern mainly the heat or the electrical conductivity, the thermal conductivity and the electrical conductivity are in a good proportional relationship.

5   The electrical resistance of a thin film is represented by a resistivity specified by its film thickness or by the area of the measured region. The volume resistivity and the sheet resistivity can be measured by a usual four probe method, and the measuring

10   method is prescribed in JIS K 7194. By the method, data can be obtained much simply and with better reproducibility than measuring the thermal conductivity of the thin film directly.

In the present invention, the reflective layer

15   preferably has a volume resistivity of from 20 $n\Omega \cdot m$ to 150 $n\Omega \cdot m$, more preferably from 20 $n\Omega \cdot m$ to 100 $n\Omega \cdot m$. A material having a volume resistivity of less than 20 $n\Omega \cdot m$ is hardly obtainable in a thin film state. Even in a case where the volume resistivity is larger than 150

20   $n\Omega \cdot m$, the sheet resistivity can be lowered by increasing the film thickness to a level exceeding 300 nm. However, according to the study by the present inventors, even if only the sheet resistivity is lowered with such a material having a high volume resistivity, no adequate

25   effect for heat dissipation is obtainable. This may be attributable to the fact that with the thick film, the heat capacity per unit area becomes large. Further, with

such a thick film, it takes time for film formation, and
the cost for the material also increases, such being
undesirable from the viewpoint of the production cost.
Further, microscopic flatness of the film surface is also
5 likely to deteriorate.

It is preferred to employ a material having a low
volume resistivity having a film thickness of at most 300
nm, whereby a sheet resistance of from 0.2 to 0.9 $\Omega/\square$
can be obtained. The volume resistivity is most
10 preferably 0.5$\Omega/\square$.

The material suitable for the present invention is
as follows.

For example, it is an Al-Mg-Si type alloy containing
from 0.3 wt% to 0.8 wt% of Si and from 0.3 wt% to 1.2 wt%
15 of Mg.

Further, with an Al alloy containing from 0.2
atomic % to 2 atomic % of Ta, Ti, Co, Cr, Si, Sc, Hf, Pd,
Pt, Mg, Zr, Mo or Mn in Al, the volume resistivity
increases in proportion to the concentration of the
20 additive element, and the hillock resistance will be
improved, and it may be employed taking into
consideration the durability, the volume resistivity, the
film forming speed, etc.

With respect to the Al alloy, if the amount of the
25 added impurity is less than 0.2 atomic %, the hillock
resistance tends to be inadequate in many cases, although
it may depend upon the film-forming condition. On the

other hand, if it exceeds 2 atomic %, the above-mentioned low resistivity can not be obtained.

In a case where the stability with time is regarded as more important, the additive component is preferably

5 Ta. Especially, when the upper protective layer 4 containing ZnS as the main component, an AlTa alloy containing from 0.5 atomic % to 0.8 atomic % of Ta is preferred as a reflective layer which satisfies all of the corrosion resistance, adhesion and high thermal

10 conductivity in good balance. Further, it is possible to obtain a preferred effect for the production such that by an addition of only 0.5 atomic % of Ta, the film-forming rate will be increased by from 30 to 40% as compared with pure Al or an Al-Mg-Si alloy.

15 In a case where the above Al alloy is used for a reflective layer, the preferred film thickness is from 150 to 300 nm. If the thickness is less than 150 nm, the heat dissipation effect will be inadequate even with pure Al. If the thickness exceeds 300 nm, the heat dissipates

20 in a vertical direction rather than a horizontal direction, whereby no contribution to the improvement of the heat distribution in the horizontal direction can be obtained, and the heat capacity of the reflective layer itself tends to be large, whereby the cooling rate of the

25 recording layer tends to be slow. Further, the microscopic flatness of the film surface is also likely to deteriorate.

Further, a Ag alloy containing from 0.2 atomic % to 5 atomic % of Ti, V, Ta, Nb, W, Co, Cr, Si, Ge, Sn, Sc, Hf, Pd, Rh, Au, Pt, Mg, Zr, Mo or Mn in Ag, is also preferred. In a case where the stability with time is regarded as more important, the additive component is preferably Ti or Mg.

In a case where the above Ag alloy is used for a reflective layer, the preferred film thickness is from 40 nm to 150 nm. If the thickness is less than 40 nm, the heat dissipation effect is inadequate even with pure Ag. If it exceeds 150 nm, the heat dissipates in a vertical direction rather than a horizontal direction, and no contribution to the improvement in the heat distribution in the horizontal direction can be obtained, and the unnecessarily thick film decreases the productivity. Further, the microscopic flatness of the film surface is also likely to deteriorate.

The present inventors have confirmed that the additive element to Al and the additive element to Ag, will increase the volume resistivity in proportion to the concentration of such an additive element.

It is usually considered that addition of an impurity tends to reduce the crystal particle size and increase the electron scattering at the grain boundaries thereby to lower the thermal conductivity. It is necessary to control the amount of the additive impurities in order to obtain the high thermal

conductivity of the material itself by increasing the crystal grain size.

The reflective layer is usually formed by sputtering or vacuum vapor deposition. The target or the material for vapor deposition contains a substantial amount of impurities, and the total amount of impurities including moisture and oxygen to be included during the film formation is required to be at most 2 atomic %. For this purpose, the final vacuum pressure of the process chamber is preferably at most 1×10^{-3} Pa.

If film formation is carried out at a final vacuum pressure poorer than 10^{-4} Pa, it is preferred to adjust the film forming rate to be at least 1 nm/sec, more preferably at least 10 nm/sec so as to prevent inclusion of impurities.

Otherwise, in a case where the intentional additive element is incorporated in an amount larger than 1 atomic %, it is preferred to adjust the film forming rate to be at least 10 nm/sec so as to minimize inclusion of additional impurities.

The film-forming conditions may sometimes influence over the crystal grain size irrespective of the amount of impurities. For example, in an alloy film having about 2 atomic % of Ta included in Al, an amorphous phase will be included between the crystal grains, and the proportions of the crystal phase and the amorphous phase depend on the film-forming conditions. For example, as the

sputtering is carried out at a low pressure, the
proportion of the crystal phase increases, the volume
resistivity decreases, and the thermal conductivity
increases.

5   The composition of impurities in the film or the
crystallizability also depends on the sputtering gas
(such as Ar, Ne or Xe) or the method for preparing the
alloy target to be used for sputtering.

       Thus, the volume resistivity in the thin film state
10   will not be determined simply by the metal material or
composition.

       In order to obtain a high thermal conductivity, it
is preferred to minimize the amount of impurities, as
mentioned above. However, on the other hand, pure metal
15   such as Al or Ag tends to be poor in the corrosion
resistance or the hillock resistance. Therefore, the
optimum composition is determined taking into the balance
of the two into consideration.

       In order to obtain higher thermal conductivity and
20   higher reliability, it is also effective to make the
reflective layer to have a multilayer structure. At that
time, at least one layer is made of the above-mentioned
material having a low volume resistivity having a
thickness of at least 50% of the total thickness of the
25   reflective layer, to obtain a substantial heat
dissipation effect, while other layers will contribute to
the improvement of the corrosion resistance, the adhesion

with the protective layer or the hillock resistance.

More specifically, among metals, Ag having the highest thermal conductivity and a low volume resistivity, has low compatibility with the protective layer containing S, and tends to deteriorate slightly quickly when subjected to repetitive overwriting.

Further, it tends to be susceptible to corrosion under a high temperature high humidity accelerated test environment.

Under these circumstances, it is effective to use Ag or a Ag alloy as a material having a low volume resistivity and to form an alloy layer containing, as the main component, Al, as an interfacial layer in a thickness of from 1 nm to 100 nm between the Ag or the Ag alloy layer and the upper protective layer. If the thickness is adjusted to be at least 5 nm, the layer tends not to have a scattered structure and can be formed uniformly.

As the Al alloy, an Al alloy containing from 0.2 atomic % to 2 atomic % of Ta, Ti, Co, Cr, Si, Sc, Hf, Pd, Pt, Mg, Zr, Mo or Mn, may be mentioned as described above.

If the thickness of the interfacial layer is less than 1 nm, no adequate protective effect will be obtained, and if it exceeds 100 nm, the heat dissipation effect tends to be sacrificed.

Use of the interfacial layer is effective particularly when the reflective layer is made of Ag or

an Ag alloy, because Ag is likely to undergo corrosion by
sulfidization when contacted with a protective layer
containing a sulfide which is regarded to be preferred in
the present invention.

5   Further, in a case where a Ag alloy reflective layer
and an Al alloy interfacial layer are employed, Ag and Al
tend to mutually diffuse to each other, and it is more
preferred to provide an interfacial oxide layer by
oxidizing the Al surface in a thickness thicker than 1 nm.

10   If the interfacial oxide layer exceeds 5 nm, especially
10 nm, thermal resistance will be created, whereby the
function as a reflective layer having an extremely high
heat dissipation property tends to be impaired, such
being undesirable.

15   The multilayer structure of the reflective layer is
effective also to obtain a desired sheet resistivity with
a desired film thickness by combining a material having a
high volume resistivity and a material having a low
volume resistivity.

20   Adjustment of the volume resistivity by alloying
simplifies the sputtering process by the use of an alloy
target. However, such will be a factor of increasing the
cost for the production of the target, or the raw
material cost for the medium. Accordingly, it is

25   effective to obtain a desired volume resistivity by
laminating a thin film of pure Al or pure Ag with a thin
film of the above additive element itself.

If the number of layers is up to three layers, the initial cost for apparatus may increase, but cost for individual media may sometimes be reduced.

It is preferred that the reflective layer is made to be a multilayer reflective layer comprising a plurality of metal films, having a total thickness of from 40 nm to 300 nm, wherein at least 50% of the thickness of the multilayered reflective layer is constituted by a thin metal layer (which may be a multilayer) having a volume resistivity of from 20 nΩ·m to 150 nΩ·m.

The thicknesses of the recording layer and the protective layers are selected taking into consideration not only the limitations from the above-mentioned aspects of the thermal characteristics, mechanical strength and reliability but also the interference effect attributable to the multilayer structure, so that the efficiency for absorbing the laser beam is good, and the amplitude of the recording signal, i.e. the contrast between the recorded state and the unrecorded state, is large.

For example, if the medium of the present invention is to be applied to rewritable DVD and interchangeability with read-only DVD is to be secured, the modulation has to be taken at a high level. Further, it is necessary that a tracking servo method so-called a DPD (Differential Phase Detection) method can be used as it is, which is commonly employed in a read only player.

Figure 6 shows a waveform of a DC retrieving signal

(a retrieving signal containing a DC component) obtained by recording and retrieving an EFM plus-modulated random signal. The modulation is defined by a ratio of I_{14}/I_{top}, where I_{14} is the signal amplitude of 14T mark and I_{top} is the signal intensity at the top of 14T mark.

I_{top}, in fact, corresponds to the reflectance in the groove of an unrecorded portion (crystal state). I_{14} depends on both the intensity difference and the phase difference of reflected lights from the crystal portion and the amorphous portion of the phase-change medium.

Basically, the intensity difference of reflected lights is determined by the difference in reflectance between the crystal state and the amorphous state. If the above modulation after recording is at least about 0.5, low jitter can be realized, and a tracking servo by the above-mentioned DPD method will properly operate.

Figure 7 illustrates an example for calculation of the difference in reflectance in a typical four-layer structure. The structure is such that a $(ZnS)_{80}(SiO_2)_{20}$ protective layer, a $Ge_{0.05}Sb_{0.69}Te_{0.26}$ recording layer, a $(ZnS)_{80}(SiO_2)_{20}$ protective layer and an $Al_{0.995}Ta_{0.005}$ reflective layer are formed on a polycarbonate substrate.

As the refractive indices of the respective layers, the actually measured values are employed. The complex refractive indices of the respective materials at a wavelength of 650 nm are 2.12-0.0i for the upper and lower protective layers, 1.7-5.3i for the reflective

layer, 1.56 for the substrate, 3.5-2.6i for the recording layer in an amorphous state (as measured in the state immediately after the film formation) and 2.3-4.1i for the recording layer in the crystal state after the

5   initialization.

The thicknesses of the recording layer, the second protective layer and the reflective layer are constant at levels of 18 nm, 20 nm and 200 nm, respectively.

So long as the dependency on the thickness of the

10 first protective layer is observed, a change in the amplitude is usually small, and the modulation depends strongly on I_{top} as the dominator, i.e. the reflectance in the crystal state. Accordingly, the reflectance in the crystal state is preferably as low as possible.

15 In the calculation example in Figure 7, the first protective layer is made of a $(ZnS)_{80}(SiO_2)_{20}$ film having a refractive index n=2.12. Here, the first minimum value d_1 is at a thickness of from 50 to 70 nm, and the second minimum value d_2 is at a thickness of from 200 to 220 nm.

20 Thereafter, the reflectance changes periodically.

The thickness of the first protective layer at which the reflectance in the crystal state becomes minimum, is determined substantially solely by the refractive index of the protective layer, provided that the recording

25 layer has a high reflectance. The minimum point thicknesses at other refractive indices can be roughly be obtained by multiplying d_1 or d_2 by 2.1/n. However, the

refractive index n of a dielectric to be used as a
protective layer is usually at a level of from 1.8 to 2.3,
and d_1 is at a level of from 60 to 80 nm.

5   If the refractive index n of the first protective
layer is smaller than 1.8, the reflectance at the minimum
point increases, whereby the modulation decreases
substantially to a level of less than 0.5, such being
undesirable. On the other hand, if it exceeds 2.3, the
reflectance at the minimum point tends to be so low that
10   20% can not be accomplished, whereby it tends to be
difficult to operate the focus servo or tracking servo.

With the compositional range of the recording layer
of the present invention, optical characteristics similar
to Figure 7 will be obtained.

15   From the viewpoint of the productivity, it is
preferred that the thickness of the first protective
layer is at most 150 nm, because at present, the film
forming speed of the dielectric protective layer by
sputtering is 15 nm/sec at most, it will be costly to
20   take a time of at least 10 seconds for the film formation.
Further, the allowance in the film thickness will be
strict, such being undesirable from viewpoint of the
productivity. Namely, as is evident also from Figure 7,
if the thickness departs by $\triangle d$ from the desired
25   thickness d_0, the reflectance changes to the same extent
in the vicinity of the first minimum value d_1 or in the
vicinity of the second minimum value d_2.

On the other hand, the thickness distribution from the viewpoint of the production is usually ±2 to 3% to d_0 because of the limitation in uniformity. Accordingly, the thinner the d_0, the smaller the $\triangle d$ i.e. the

5 variation degree in the thickness, and such is advantageous, since the variation in the reflectance in the disk plane or among disks can be suppressed.

Accordingly, in the case of an inexpensive stationary facing type sputtering apparatus having no

10 mechanism for revolution and rotation of a substrate, it is advisable to employ the film thickness in the vicinity of the first minimum value d_1.

On the other hand, a thick protective layer has a large effect for suppressing deformation of the substrate

15 surface at the time of repetitive overwriting. Accordingly, if improvement of the repetitive overwriting durability is of importance, it is advisable to employ a film thickness in the vicinity of the second minimum value d_2.

20 With a medium for recording or retrieving by applying a recording or retrieving laser beam via the substrate, it is necessary to protect the substrate from the heat generated during the recording, by making the first protective layer thick to some extent. During the

25 recording, the recording layer becomes at least 500 to 600°C for a period of about 100 nsec. For this purpose, the film thickness is preferably at least 50 nm. If the

thickness is less than 50 nm, microscopic deformation will be accumulated on the substrate by repetitive recording, which causes a noise or defect. Especially when the substrate is made of a thermoplastic material

5   such as polycarbonate, the thickness of the protective layer becomes important.

Now, an optical recording method will be described which is preferably employed in combination with the medium of the present invention.

10   A preferred first recording method comprises recording mark length-modulated information on the above described recording medium by a plurality of record mark lengths, wherein a recording laser beam having an erasing power Pe capable of crystallizing amorphous phase is

15   applied between record marks, and

when the time length of one record mark is represented by nT (wherein T is the reference clock period, and n is an integer of at least 2), the time length nT of the record mark is divided in the order of:

20   $\eta_1 T$, $\alpha_1 T$, $\beta_1 T$, $\alpha_2 T$, $\beta_2 T$, . . .,

$\alpha_i T$, $\beta_i T$, . . ., $\alpha_m T$, $\beta_m T$, $\eta_2 T$

wherein m is a pulse dividing number, and m=n-k, where k is an integer of $0 \leqq k \leqq 2$,

$\Sigma_i (\alpha_i + \beta_i) + \eta_1 + \eta_2 = n$, η_1 is a real number of $\eta_1 \geqq 0$, η_2

25   is a real number of $\eta_2 \geqq 0$, provided $0 \leqq \eta_1 + \eta_2 \leqq 2.0$,

$\alpha_i (1 \leqq i \leqq m)$ is a real number of $\alpha_i > 0$, $\beta_i (1 \leqq i \leqq m)$ is a real number of $\beta_i > 0$, $\Sigma \alpha_i < 0.5n$,

α_1=0.1 to 1.5, β_1=0.3 to 1.0, β_m=0 to 1.5, α_i=0.1 to 0.8 ($2 \leqq i \leqq m$), and

when i is $3 \leqq i \leqq m$, $\alpha_i + \beta_{i-1}$ is within a range of from 0.5 to 1.5 and is constant irrespective of i,

5   a recording laser beam having a writing power Pw of Pw>Pe, sufficient to melt the recording layer, is applied within the time of $\alpha_i T$ ($1 \leqq i \leqq m$), and a recording laser beam having a bias power Pb of 0<Pb$\leqq$0.2Pe is applied within the time of $\beta_i T$($1 \leqq i \leqq m$) (provided that within $\beta_m T$,

10   the bias power may be 0<Pb$\leqq$Pe).

By employing the above recording method in combination with the above described medium, it is possible to accurately control the cooling rate at the time of resolidification of the recording layer and to

15   carry out high density mark length modulation recording with the shortest mark length being at most 0.5 μm within a linear velocity range of at least from 3 m/s to 8 m/s, or by adjusting the recording conditions, within a wider linear velocity range of from 1 m/s to 15 m/s, and it is

20   possible to accomplish repetitive overwriting of at least 1,000 times and to realize a low jitter of less than 10% of the reference clock period T.

In order to realize the high density mark length modulation recording as described above, firstly, a laser

25   beam having a wavelength of from 350 to 680 nm is focused on the recording layer through an object lens having a numerical aperture NA of from 0.55 to 0.9, to form a very

small focused laser beam spot.

More preferably, NA is from 0.55 to 0.65. If NA exceeds 0.65, the influence of aberration due to an inclination of the optical axis becomes substantial,
5 whereby it will be necessary to reduce the distance between the object lens and the recording surface. Accordingly, in a case where a focused laser beam is applied through a substrate having a thickness of about 0.6 mm, as in the case of DVD, the upper limit of NA will
10 be about 0.65.

And, as shown in Figure 8, by modulating the recording laser power to have at least three values, it is possible to broaden the power margin and the linear velocity margin during recording.

15 In Figure 8, the start position of the first recording pulse $\alpha_1 T$, the final position of the final off pulse $\beta_m T$, does not necessarily agree to the start position and the final position of the initial recording signal. Within the range of $0 \leqq \eta_1 + \eta_2 \leqq 2.0$, $\eta_1 T$ may be
20 placed at the front, and $\eta_2 T$ may be placed at the end. It is effective to finely adjust the length of $\eta_1 T$ or $\eta_2 T$ depending upon the lengths of the land portions or the length of marks before and after the particular mark, in order to form the mark accurately.

25 Otherwise, by changing only β_m depending upon the mark length nT, a good mark may sometimes be formed. The final β_m may be 0. For example, a long mark such as 11T

mark among 3T to 11T marks in EFM modulation or 14T mark
among 3T to 14T in EFM plus modulation, is likely to
accumulate heat, and it is advisable to prolong the final
β_m to prolong the cooling time.

5   On the other hand, in the case of a short mark such
as 3T mark, it is advisable to shorten β_m. The range of
such adjustment is about 0.5. In the case of high
density recording exceeding a linear recording density of
so-called DVD, an adequate recording signal quality can
10   be obtained even without carrying out such fine
adjustment.

Further, the mark shape can be controlled also by
changing the intensity of the bias power Pb. Figure 9
shows an example of changes with time of the temperature
15   at one point on the recording layer, when two recording
pulses were applied. This represents the temperature
changes at the position where recording pulse P1 is
applied in the case where recording pulse P1, an off
pulse, recording pulse P2 were continuously applied while
20   moving the beam relative to the medium. Line (a)
represents a case where Pb=Pe, and line (b) represents a
case where Pb≒0.

In Figure 9(b), the bias power Pb was almost zero in
the off pulse section, whereby TL′ lowered to a point
25   sufficiently lower than the melting point, and the
cooling rate to that point was substantial. Thus, the
amorphous mark is formed by the melting at the time of

irradiation of the recording pulse P1, followed by rapid cooling during the subsequent off pulse period.

On the other hand, in Figure 9(a), erasing power Pe is irradiated even during the off pulse section, whereby the cooling rate after irradiation with the first recording pulse P1, is slow, and the lowest temperature TL reached by the temperature drop in the off pulse section will remain in the vicinity of the melting point Tm, and the temperature is further raised by the subsequent recording pulse P2 to a point in the vicinity of the melting point Tm, whereby an amorphous mark can hardly be formed.

It is important to take a sharp temperature profile as shown in Figure 9(b), for the medium of the present invention, in order to suppress the crystallization in a high temperature region and to obtain a good amorphous mark. Namely, the recording layer of the medium of the present invention shows a high crystallization rate only in the high temperature region immediately below the melting point, and accordingly, the recrystallization can be suppressed by adopting the profile of (b) whereby the recording layer temperature will not stay in the high temperature region so long.

Or, it may be considered that formation of crystal nuclei in a relatively low temperature range which is close to the crystallizing temperature Tc, is not governing in the every erasing process, and as Sb

clusters which were formed during the above-mentioned
initialization and which can serve as crystal nuclei, are
constantly present, only the crystal growth in the high
temperature region is governing.

5   Accordingly, by controlling the cooling rate and
TL', recrystallization can be suppressed substantially
completely, whereby an amorphous mark having a clear
profile which substantially agrees to the melt region,
can be obtained, and jitter of the mark edge can be

10   reduced.

On the other hand, with the GeTe-Sb_2Te_3 pseudo binary
alloy, there will be no substantial difference in the
process for forming amorphous marks between the
temperature profiles of (a) and (b) in Figure 9, because

15   this material shows recrystallizability in a wide
temperature range, especially even in a low temperature
range close to the crystallizing temperature Tc, although
the crystallization speed may be slightly slow. Or, with
this material, formation of crystal nuclei in a

20   temperature range relatively close to Tc and formation of
crystals in a temperature range close to Tm are rate-
controlling, whereby it is considered that
recrystallization takes place at a relatively low speed
in a wide temperature range as a whole.

25   Also with GeTe-Sb_2Te_3, there may be a case where
coarse grains are suppressed by using an off pulse with
Pb<Pe. However, if Pb/Pe$\leqq$0.2, crystallization in the

vicinity of Tc is suppressed too much, whereby erasing
performance rather tends to deteriorate.

Whereas, with the material for the recording layer
of the present invention, it is considered that at a
relatively low temperature close to Tc, no substantial
crystallization proceeds, and it is preferred to adopt
Pb/Pe$\leq$0.2. Or, more specifically, it is preferred to
adopt 0$\leq$Pb$\leq$1.5 (mW), and Pb which is as low as possible
so long as the tracking servo is stable, is employed.
And, an off pulse is positively employed to secure rapid
cooling, whereby the edge of an amorphous mark can
distinctly be formed, such being desirable.

In the pulse-dividing method shown in Figure 8, it
is most effective to set only the front end recording
pulse $\alpha_1 T$ longer than the subsequent pulses $\alpha_i T$ and to
set only the front end and rear end off pulse widths $\beta_1 T$
and $\beta_m T$ differently from other off pulses, in order to
secure a good balance of characteristics of long marks
and short marks.

The forward end pulse $\alpha_1 T$ has no remaining heat
effect, whereby it takes a slightly long time for
temperature rise. Otherwise, it is effective to set the
recording power of the front end pulse higher than the
subsequent pulses.

Further, the pulse control can be simplified by
synchronizing the switching of pulses to the clock period
T. Figure 10 shows a pulse-dividing method which is

suitable for mark length modulation recording and wherein
the pulse control circuit is simple. As a pulse-dividing
method for recording the mark length modulated data of
(a), (b) shows a case where m=n-1, and (c) shows a case
5   where m=n-2. In (b) and (c), T is omitted to make the
graphs simple. In each case, $\alpha_i (2 \leqq i \leqq m)$ and $\beta_i (2 \leqq i \leqq m-1)$ are constant irrespective of i, $\alpha_1 \geqq \alpha_i$,
$\alpha_i + \beta_{i-1} = 1.0 (3 \leqq i \leqq m)$, and the rear end of the recording
pulse of $\alpha_i (2 \leqq i \leqq m)$ is synchronized to the clock pulse.

10   Further, it is effective to adjust Pb to be the same
as retrieving laser power Pr in order to simplify the
circuit. It is necessary to set only the front pulse $\alpha_1 T$
longer than the subsequent pulses in order to obtain a
good balance of recording of short marks and long marks
15   in a so-called eye patterns. Otherwise, only the front
pulse may be made to have a higher power than the
subsequent pulses.

Such pulses can be accomplished by three types of
gate generating circuits as shown in Figure 11 and by
20   determining the priority among them.

Figure 11 is a view illustrating an embodiment of
the pulse-generating method by the recording method of
the present invention. In Figure 11, (a) represents the
clock signal, (b) represents the data signal, and (c) to
25   (e) represent gate signals generated from three types of
gate generating circuits i.e. (c) Gate 1, (d) Gate 2, and
(e) Gate 3. The pulse-dividing method of the present

invention can be accomplished by preliminarily deciding
the priority among these three types of gate signals.

Gate 1 decides only the recording pulse generating
section $\alpha_1 T$, and Gate 2 decides the timing for
generating a predetermined number of subsequent pulses
$\alpha_i T (2 \leqq i \leqq m)$. Here, the pulse width α_i has a constant
value α_c within $2 \leqq i \leqq m$. Gate 3 generates the off pulse
generating section $\beta_i T$. When Gate 3 is on (at a high
level), Pb is generated, and when it is off (at a low
level), Pe is generated.

By deciding the timing for the build-up of only α_i
independently, β_1 can be made to have a value different
from β_i.

It is advisable to synchronize the rise timing of
gate 3 and Gate 1. Gate 1 and Gate 2 generate Pw,
respectively. However, when Gate 1 and Gate 2 are "on",
they have priority over Gate 3. If the delay time T_1 and
α_1 of Gate 1, and the delay time (T_1+T_2) and α_c of Gate 2
are specified, the strategy in Figure 10 can be
specified.

Here, if T_1 is at least 1T, such represents the
pulses in the case of m=n-1 in Figure 10(b), and if T_1 is
less than 1T and the number of subsequent pulses is
reduced by one, such represents the pulses in the case of
m=n-2 in Figure 10(c). Here, by adjusting $\alpha_1 T$ and
$\beta_{m-2} T$ to be longer than the case of m=n-1, the formed
mark length is made to be nT.

As another application of the present invention, the following recording method is preferably employed in order to obtain a signal quality equivalent to read-only DVD at least at the time of retrieving, with a recording density of at least equal to read-only DVD.

Namely, this is an optical recording method wherein recording or retrieving data is carried out by focusing a laser beam having a wavelength of from 350 to 680 nm on the recording layer through the substrate by an object lens having a numerical aperture NA of from 0.55 to 0.9, wherein m=n-1 or m=n-2, $0 \leqq Pb \leqq 1.5$ (mW), and Pe/Pw is from 0.3 to 0.6.

And, it is preferred to satisfy the following conditions:

$\alpha_1 = 0.3$ to 1.5,

$\alpha_1 \geqq \alpha_i = 0.2$ to $0.8 (2 \leqq i \leqq m)$,

$\alpha_i + \beta_{i-1} = 1.0 (3 \leqq i \leqq m)$,

$\beta_m = 0$ to 1.5

The ratio of Pe/Pw is maintained to be constant, so that the erasable range is broadened by increasing the erasing power when a power fluctuation has occurred, and the record mark is large with a high power. If Pe/Pw is less than 0.3, Pe is always low, and erasing tends to be inadequate. On the other hand, if it exceeds 0.6, Pe tends to be excessive, and it is likely to lead to reconversion to an amorphous state in the vicinity of the center of the laser beam, whereby erasing by complete

recrystallization tends to be difficult. Further, the
amount of energy irradiated to the recording layer tends
to be too much, whereby the recording layer is likely to
deteriorate by repetitive overwriting.

5   With the recording layer having the composition of
the present invention, good jitter is obtainable
especially when α_i is within a small range. Accordingly,
it is advisable to set $\Sigma \alpha_i < 0.5n$ and to reduce $(\Sigma \alpha_i)/n$
as k is small. Namely, when k=0 or k=1, it is preferred

10   that $(\Sigma \alpha_i) < 0.4n$, and when k=2, it is preferred that
$(\Sigma \alpha_i) < 0.5n$.

Preferably, in order to apply such a recording
pulse-dividing method to overwriting at a linear velocity
of at least 3 m/s, in the recording layer of

15    $Ge_x(Sb_yTe_{1-y})_{1-x}$ of the present invention, y is adjusted to
be at least 0.72, and when it is applied to overwriting
at a linear velocity of 7 m/s, y is adjusted to be at
least 0.74. Namely, the ratio of Sb/Te is made to be Sb-
rich at a level of at least 2.57, more preferably at

20   least 2.85.

It is one of the preferable features of the present
invention that stability of amorphous marks is high and
the storage stability is also good, even if the
composition of the recording layer is made to be Sb-rich

25   as described above.

JP-A-8-22644 discloses a AgInSbTe recording layer
having Ag and In added in a total amount of about 10

atomic % to a composition in the neighborhood of $Sb_{0.7}Te_{0.3}$. However, this recording layer has a problem in the storage stability such that if the Sb/Te ratio in this AgInSbTe recording layer is made to be at least

5   2.57, the amorphous marks tend to be extremely unstable.

Now, this will be further explained with reference to a test example. Here, reference is made to a case where EFM plus modulated mark length recording is carried out in which to record a mark with a length of nT,

10   recording is carried out by means of an optical system having a wavelength of from 630 to 680 nm and NA=0.6 within a range of a linear velocity of from 2 m/s to 5 m/s, by dividing the recording pulses into n-1.

As an embodiment of the recording layer of the

15   present invention, $Ag_{0.05}Ge_{0.05}Sb_{0.67}Te_{0.23}$ (Sb/Te$\fallingdotseq$2.91), and as an embodiment of the above AgInSbTe recording layer, $Ag_{0.05}In_{0.05}Sb_{0.63}Te_{0.27}$ (Sb/Te$\fallingdotseq$2.33) is employed.

Both the recording layer having the composition of the present invention and the above AgInSbTe recording

20   layer have substantially the same optical constant. Accordingly, by employing the same layer structures, it was possible to obtain equal reflectance and modulation. Thus, thermally equivalent layer structures can be applied.

25   The thickness of the first protective layer is made to be 100 nm, the recording layer 20 nm, the second protective layer 20 nm and the reflective layer 200 nm,

and in each case, β_i=about 0.5 ($1\leqq i\leqq n-1$), Pw=10 to 14 (mW), Pe/Pw=0.5, and Pb$\doteqdot$0.

Here, with the conventional $Ag_{0.05}In_{0.05}Sb_{0.63}Te_{0.27}$ recording layer, it is preferred that α_1=0.8 to 1.2, and α_i=0.4 to 0.6($2\leqq i\leqq n-1$). Especially when α_1=1.0, α_i($2\leqq i\leqq n-1$)=0.5, and β_m=0.5, $\Sigma\alpha_i$ necessarily becomes 0.5n irrespective of n.

On the other hand, with the $Ag_{0.05}Ge_{0.05}Sb_{0.67}Te_{0.23}$ recording layer of the present invention, α_1=0.3 to 0.5, and α_i=0.2 to 0.4($2\leqq i\leqq n-1$) become preferred ranges. More specifically, α_1 may be 0.6, and α_i($2\leqq i\leqq n-1$) may be 0.35. In this case, when n=3, $\Sigma\alpha_i\doteqdot0.32n$, and when n=at least 4, $\Sigma\alpha_i\doteqdot0.33n$ to $0.34n$.

This means that with the medium of the present invention, it is possible to reduce the average irradiation power to be applied for recording and to shorten the substantial recording pulse irradiation time to a level of $\Sigma\alpha_i<0.4n$.

The following effects can thereby be obtained.

(1) Deterioration of the quality of the recording signal due to high power recording can be reduced. The problem of high power recording is attributable to the fact that the optical energy applied to the recording layer tends to be too much, and such energy will accumulate in the recording layer. Accordingly, the cooling rate tends to be slow, whereby recrystallization of amorphous marks is likely to take place, or

deterioration during repetitive overwriting tends to be remarkable.

By providing an off pulse section with a low power, the average input power is suppressed, and by releasing the heat in a in-plane direction by the reflective layer having a high thermal conductivity, even during high power recording, it is possible to suppress the adverse effect by accumulation of the heat at the rear end portions of marks, particularly at the rear end portions of long marks, and it is possible to form good long marks.

(2) Thermal damages of the respective layers during repetitive overwriting can be reduced, whereby repetitive durability can be improved. By reducing a thermal damage for every operation, it is possible to suppress deformation of e.g. a plastic substrate which is weak against heat. Further, the range where the damage occurs, can be limited to a narrower range to the center portion of the laser beam profile.

Especially, with long marks of n=at least 4 wherein the heat is likely to be accumulated, the effect of reducing the proportion of substantial recording energy irradiation $(\Sigma \alpha_i)/n$, is large. Accordingly, it is possible to reduce the adverse effect to the medium even at a low linear velocity of at most 5 m/s where the medium is susceptible to a thermal damage.

In the present invention, the repetitive overwriting

durability can be improved as described above, and it is possible to accomplish overwriting in a number of times larger by one figure over conventional overwriting.

Further, the recording layer is made of a thin film

5   comprising, as a main component, a $Ge_x(Sb_yTe_{1-y})_{1-x}$ alloy $(0.045 \leqq x \leqq 0.075$, and $0.74 \leqq y < 0.8)$, and the recording pulse-dividing method is made variable depending upon the linear velocity, whereby it becomes possible to carry out overwriting at a linear velocity within a wide range

10   including from 3 m/s to 8 m/s.

Namely, in the pulse-dividing method shown in Figure 8, k in m=n-k is made constant, and either Pb/Pe or α_i is simply decreased, as the linear velocity at the time of overwriting is low.

15   Further, the clock period may be changed depending upon the linear velocity in order to maintain the recording density to be constant, or Pw and Pe may be changed to maintain the optimum conditions at the respective linear velocities.

20   The present invention further provides a method for recording a so-called EFM plus modulated signal wherein the shortest mark length will be from 0.35 to 0.45 μm, at both 1-time velocity and 2-times velocity of the standard retrieving linear velocity of DVD. Here, the standard

25   retrieving linear velocity of DVD is 3.49 m/s.

Namely, this is an optical recording method, wherein recording or retrieving of data is carried out by

focusing a laser beam having a wavelength of from 600 to 680 nm on the recording layer through an object lens having a numerical aperture NA of from 0.55 to 0.65, with the shortest mark length being within a range of from 0.35 to 0.45 μm, and wherein:

n is an integer of from 1 to 14,

m=n-1,

Pb is constant within a range of $0 \leqq Pb \leqq 1.5$ (mW) irrespective of the linear velocity,

Pe/Pw is changeable depending upon the linear velocity within a range of from 0.4 to 0.6,

(i) within a linear velocity of from 3 to 4 m/s, the reference clock period T is To,

α_1=0.3 to 0.8,

$\alpha_1 \geqq \alpha_i$=0.2 to 0.4 and is constant irrespective of i $(2 \leqq i \leqq m)$,

$\alpha_2 + \beta_1 \geqq 1.0$

$\alpha_i + \beta_{i-1}$=1.0 $(3 \leqq i \leqq m)$,

β_m=0.3 to 1.5, and

a recording laser beam having a writing power Pw1 is irradiated within the time of $\alpha_i T (1 \leqq i \leqq m)$,

(ii) within a linear velocity of from 6 to 8 m/s, the reference clock period T is To/2,

α'_1=0.3 to 0.8,

$\alpha'_1 \geqq \alpha'_i$=0.3 to 0.5 and is constant irrespective of i $(2 \leqq i \leqq m)$,

$\alpha'_1 + \beta'_{i-1}$=1.0 $(3 \leqq i \leqq m)$,

$\beta'_m = 0$ to 1.0, and

a recording laser beam having a writing power Pw2 is irradiated within the time of $\alpha_i T (1 \leqq i \leqq m)$,

wherein $\alpha'_1 > \alpha_i (2 \leqq i \leqq m)$, and $0.8 \leqq Pw1/Pw2 \leqq 1.2$.

5   According to the test results obtained by the present inventors, so long as the pulse-dividing method as shown in Figure 10 is employed, particularly good jitter was obtained by this setting.

Here, if $\alpha_2 + \beta_1 = 1.0$, independent parameters relating to the pulse width will be three i.e. α_1, α_i and β_m,
10   whereby the recording signal source can further be simplified, such being preferred.

Further, n may not necessarily take every integer of from 1 to 14, and in EFM plus modulation, n takes an integer of from 3 to 11 and 14. Further, (1,7)RLL-NRZI
15   (Run Length Limited-Non Return To Zero Inverted) symbols, etc. may also be used.

Further, in order to make the recording density to be constant, it is common to set the clock period at the time of recording at 1-time velocity to be twice the
20   clock period at the time of recording at 2-times velocity.

The present invention is effective not only for the system wherein recording is carried out over the entire record region while maintaining a constant linear
25   velocity as described above (CLV (constant linear velocity) system) but also for a system wherein recording

is carried out over the entire recording region at a
constant rotational angular velocity (CAV (constant
angular velocity) system). Or, it is effective also for
a ZCLV (Zoned CLV) system wherein the radial direction is
5 divided into a plurality of zones, and within the same
zone, overwriting is carried out by the CLV system.

Optical disks have various diameters such as 86 mm,
90 mm (single CD size), 120 mm (CD size) and 130 mm, and
the recording region ranges from a radius of from 20 to
10 25 mm to a largest radius of about 65 mm. Here, the
difference in the linear velocity as between the inner
and outer diameter becomes as large as three times at the
maximum.

In general, in high density mark length recording,
15 the linear velocity range wherein the phase-change medium
exhibits good overwriting characteristics, is within a
range of a linear velocity ratio of about 1.5 times. As
the linear velocity increases, the cooling rate of the
recording layer becomes high, whereby an amorphous mark
20 will readily be formed. However, the time during which
the temperature is maintained at a level of at least the
crystallization temperature, becomes short, whereby
erasing tends to be difficult. On the other hand, if the
linear velocity decreases, erasing will be easy, but the
25 cooling time of the recording layer will be slow, whereby
recrystallization is likely to take place, and good
amorphous marks tend to be hardly formed.

To solve this problem, the thickness of the
reflective layer may be varied as between the inner and
outer diameter, so that the degree of the heat
dissipation effect by the reflective layer will be large
5 at the inner periphery. Otherwise, it has also been
proposed that the composition of the recording layer is
modified so that the crystallization speed is increased
at the outer diameter, or the critical cooling rate
required for the formation of an amorphous state, is
10 lowered at the inner diameter. However, it is not easy
to prepare a disk having such a distribution.

Whereas, by the combination for the medium and the
optical recording method of the present invention, so
long as the linear velocity at the outer-most diameter of
15 the disk, i.e. the maximum linear velocity, is at most 10
m/s, good recording is possible even by a CAV system or
by a ZCLV system.

In order to apply the present invention to a medium
wherein the linear velocity radially varies as mentioned
20 above, it is preferred that the recording region is
radially divided into a plurality of zones, so that the
reference clock frequency of data and the pulse-dividing
method may be changed from one zone to another.

Namely, this is a method for recording information
25 by a plurality of mark lengths by rotating the optical
information recording medium having a predetermined
recording region at a constant angular speed, wherein the

medium is rotated so that the linear velocity at the
inner-most diameter of the recording region will be from
2 to 4 m/s, and the linear velocity at the outer-most
diameter of the recording region will be from 6 to 10 m/s,
5 and the recording region comprises a plurality of
radially divided zones, and the reference clock period T
is changed so that the recording density in each zone
will be substantially constant depending upon the average
linear velocity.

10 Here, the pulse-dividing number m is made constant
irrespective of the zone, and the Pb/Pe ratio and/or α_i
(i is at least one of $1 \leq i \leq m$) is simply decreased from
the outer zone towards the inner zone, whereby it is
possible to prevent the possibility that at the inner
15 diameter portion with a low linear velocity, formation of
amorphous marks becomes incomplete due to an insufficient
cooling rate. Here, "α_i (i is at least one of $(1 \leq i \leq m)$
is simply decreased" means, for example, among α, α_2, ..., α_m, only α_2 is decreased.

20 More specifically, it is preferred to employ a
pulse-dividing method depending upon the linear velocity
on the basis of the pulse-dividing method shown in Figure
10, whereby the circuit for the variable pulse-dividing
method can be simplified. At that time, it is convenient
25 that the recording region is divided into p zones in the
radial direction, and the clock period and the pulse-
dividing method are changed for every zone, rather than

they are continuously changed in the radial direction.

In the present invention, it is preferred that the record region is radially divided into p zones, and when the inner-most diameter side is referred to as the first zone, the outer-most diameter side is referred to as the p-th zone, and in the q-th zone (wherein q is an integer of $1 \leqq q \leqq p$), the angular velocity is represented by ω_q, the average linear velocity is represented by $<V_q>_{ave}$, the maximum linear velocity is represented by $<V_q>_{max}$, the minimum linear velocity is represented by $<V_q>_{min}$, the reference clock period is represented by T_q, and the time length of the shortest mark is represented by $n_{min}T_q$,

$<V_p>_{ave}/<V_1>_{ave}$ is preferably within a range of from 1.2 to 3, and $<V_q>_{max}/<V_q>_{min}$ is at most 1.5. Within the same zone, the same clock period and the same pulse-dividing method are employed, but the linear velocity range which can be covered by the same pulse-dividing method, is usually up to about 1.5 times.

And, within the same zone, ω_q, T_q, α_i, β_i, Pe, Pb and Pw are constant, the physical length $n_{min}T_q<V_q>_{ave}$ of the shortest mark is at most 0.5 μm, $T_q<V_q>_{ave}$ is substantially constant with respect to all q of $1 \leqq q \leqq p$, and

m=n-1 or m=n-2,

α_1=0.3 to 1.5,

$\alpha_1 \geqq \alpha_i$=0.2 to 0.8 $(2 \leqq i \leqq m)$,

$\alpha_1 + \beta_{i-1}$=1.0 $(3 \leqq i \leqq m)$,

$0 \leqq Pb \leqq 1.5$ (mW),

$0.4 \leqq Pe/Pw \leqq 0.6$.

Here, it is preferred that when m=n-1, α_1=0.3 to 1.5, and α_i=0.2 to 0.5, and when m=n-2, α_1=0.5 to 1.5, and
5   α_i=0.4 to 0.8.

It is important that the pulse-dividing method is changed in accordance with the following rule. For every zone, Pb, Pw, the Pe/Pw ratio, α_i, β_1 and β_m are variable, and recording is carried out by simply
10   decreasing at least α_i(α_i is at least one of $2 \leqq i \leqq m$) from the outer zone towards the inner zone.

It is preferred that the change in α_i for every zone is by every 0.1T or by every 0.01T.

Here, by adding a high frequency base clock generating circuit with a frequency of about 1/100
15   relative to the reference clock period T_p at the outer-most diameter zone, T_q and the divided pulse length in every zone can be generated as multiples of this base clock.

20   With DVD, the reference clock frequency at 1-time velocity is about 26 MHz, and the base clock frequency may be about 2.6 GHz at the maximum, usually about 260 MHz i.e. one figure less than the maximum frequency.

Further, when Pw_{max} is the maximum value and Pw_{min} is
25   the minimum value of Pw in the record region, it is possible to set $Pw_{max}/Pw_{min} \leqq 1.2$, Pe=Pw=0.4 to 0.6 and $0 \leqq Pb \leqq 1.5$ (mW). The setting ranges of the three types of

powers can thereby be defined, whereby the power-
generating circuit can be simplified.

In the present invention, it is further possible to
accommodate every linear velocity simply by changing only
5   the pulse-dividing method while maintaining Pw, the Pe/Pw
ratio and Pb to be constant. Further, β_m may be made
constant irrespective of the zone, and only α_1 and α_m
may be made zone-dependent parameters. This is extremely
useful to simplify the recording pulse control circuit of
10   the drive.

In the present invention, recording may be carried
out by setting an imaginary zone on the recording medium
from the radial positional information of the optical
head during recording, or a zone structure may be
15   physically provided on the disk in accordance with an
address information or a zone information preliminarily
recorded on the disk. Whether the zone is imaginary or
physical, a recording pulse-dividing method suitable for
the linear velocity determined by the zone, may be
20   selected.

Now, another example in which the optical recording
method of the present invention is applied to a ZCAV
system, will be described.

The record region is radially divided into p zones,
25   and the inner-most diameter side is referred to as the
first zone, the outer-most diameter side is referred to
as the p-th zone, and in the q-th zone (wherein q is an

integer of $1 \leq q \leq p$), the angular velocity is represented
by ω_q, the average linear velocity is represented by
$<V_q>_{ave}$, the maximum linear velocity is represented by
$<V_q>_{max}$, the minimum linear velocity is represented by
5    $<V_q>_{min}$, the reference clock period is represented by T_q,
and the time length of the shortest mark is represented
by $n_{min}T_q$.

In the ZCAV system, it is necessary to make the
reference clock T_q of recording data to be smaller
10   towards the outer-most peripheral zone to make the
recording linear density to be substantially constant.

Namely, T_q is changed depending upon the zone so that
$Tq<V_q>_{ave}$ will be substantially constant with respect to
all q of $1 \leq q \leq p$. Here, substantially constant includes
15   an error of about ±1%.

Further, to bring the maximum linear velocity and
the minimum linear velocity in the same zone within
predetermined ranges, the width of the zone is determined
to satisfy:

20   $(<V_q>_{max}-<V_q>_{min})/(<V_q>_{max}+<V_q>_{min})<10\%$ (2)

Namely, $(<V_q>_{max}-<V_q>_{min})$ is adjusted to be less than
10% of $(<V_q>_{max}+<V_q>_{min})$, and the width of the q-th zone
may be up to a radial position less than ±10% of the
average radius $<r_q>_{ave}$. More preferably, $(<V_q>_{max}-<V_q>_{min})$
25   is less than 5% of $(<V_q>_{max}+<V_q>_{min})$.

With respect to the widths of zones, the record
region may be equally divided in radial direction, but so

long as the above conditions are satisfied, the division
may not be equal division. For example, a recording
region with a width of from 30 to 40 mm may usually be
divided into at least 10 zones, although the division may
5   vary depending upon the width of the recording region.

According to the study by the present inventors,
even with the shortest mark length of about 0.4 μm, the
value of jitter is a practical level so long as the
formula (2) is satisfied.

10   The foregoing two conditions are conditions to make
the recording linear density to be constant and
accordingly to make the physical length of marks for the
channel bit length to be constant. Here, the channel bit
length is a length per one channel bit along the track.

15   To secure the retrieving interchangeability with DVD,
it is preferred to limit the variation of the channel bit
length vT to be less than about ±1%, when the reference
retrieving speed V is about 3.5 m/s and the reference
clock period T is about 38.2 nsec.

20   To satisfy this condition with a ZCAV medium, the
following formula (3) must be satisfied:

$$(<V_q>_{max}-<V_q>_{min})/(<V_q>_{max}+<V_q>_{min})<1\% \qquad (3)$$

Namely, $(<V_q>_{max}-<V_q>_{min})$ is adjusted to be less than
1% of $(<V_q>_{max}+<V_q>_{min})$, and the width of the q-th zone may
25   be up to a radial position less than ±1% of the average
radius $<r_q>_{ave}$. For this purpose, the recording region is
divided into at least 200 zones. And,

$$T_q<V_q>_{ave}=vT \qquad (4)$$

wherein $T_q<V_q>_{ave}$ is made to be substantially constant with respect to all q of $1\leqq q\leqq p$. Here, substantially constant includes an error of about ±1%.

5   Thus, even with a ZCAV system, equal density recording irrespective of the radius, can be approximately attainable, whereby retrieving by a CLV system will be possible, and interchangeability with a DVD player of a CLV system will be increased.

10   The widths of zones may be made narrower, as the case requires.

Now, an optical recording method will be explained whereby a recording density equal to DVD can be obtained under the conditions as described above.

15   Namely, the present invention provides an optical recording method wherein recording or retrieving of data is carried out by focusing a laser beam having a wavelength of from 600 to 680 nm on the recording layer through the substrate by an object lens having a

20   numerical aperture NA of from 0.55 to 0.65, and wherein:

the inner-most diameter of the record region is within a range of the radius being from 20 to 25 mm, the radius of the outer-most diameter is within a range of from 55 to 60 mm, and the average linear velocity in the

25   inner-most diameter zone is from 3 to 4 m/s,

when in the q-th zone (wherein q is an integer of $1\leqq q\leqq p$), the angular velocity is represented by ω_q, the

average linear velocity is represented by $<V_q>_{ave}$, the

maximum linear velocity is represented by $<V_q>_{max}$, the

minimum linear velocity is represented by $<V_q>_{min}$, the

reference clock period is represented by T_q, and the time

5   length of the shortest mark is represented by $n_{min}T_q$,

    n is an integer of from 1 to 14,

    m=n-1,

    ω_q, Pb and Pe/Pw are constant irrespective of the

zone,

10     $T_q<V_q>_{ave}$ is substantially constant with respect to

all q of $1 \leqq q \leqq p$, and

    $(<V_q>_{max}-<V_q>_{min})/(<V_q>_{max}+<V_q>_{min})<10\%$,

    (i) in the first zone,

    $\alpha^1_1=0.3$ to 0.8,

15     $\alpha^1_1 \geqq \alpha^1_i=0.2$ to 0.4 and is constant irrespective of i

$(2 \leqq i \leqq m)$,

    $\alpha^1_2+\beta^1_1 \geqq 1.0$,

    $\alpha^1_i+\beta^1_{i-1}=1.0$ $(3 \leqq i \leqq m)$,

    (ii) in the p-th zone,

20     $\alpha^p_1=0.3$ to 0.8,

    $\alpha^p_1 \geqq \alpha^p_i=0.3$ to 0.5 and is constant irrespective of i

$(2 \leqq i \leqq m)$,

    $\alpha^p_i+\beta^p_{i-1}=1.0$ $(2 \leqq i \leqq m)$, and

    (iii) in other zones, $\alpha^1_i \leqq \alpha^q_i \leqq \alpha^p_i$ $(2 \leqq i \leqq m)$, and

25   α^q_1 is a value between α^1_1 and α^p_1.

    When the inner-most diameter of the record region is

within a range of the radius being from 20 to 25 mm and

the radius of the outer-most diameter is within a range of from 55 to 60 mm, the radial width of the record region will be from about 30 to 40 mm. And, the disk is rotated at an equal angular velocity so that $<V_1>_{ave}=3$ to

5 4 m/s in the inner-most peripheral first zone.

With respect to the first zone and the p-th zone, recording is carried out under the above conditions, and with respect to other zones (the q-th zone of $2 \leqq q \leqq p-1$), $\alpha^1_i \leqq \alpha^q_i \leqq \alpha^p_i$ ($2 \leqq i \leqq m$), and α^q_1 is a value between α^1_1

10 and α^p_1. Here, the value of α^q_1 is preferably set by every 0.1T or by every 0.01T.

Preferably, $\alpha^1_1 \geqq \alpha^q_1 \geqq \alpha^p_1$ (provided $\alpha^1_1 > \alpha^p_1$).

Further, Pb, Pe/Pw, β_1 and β_m are constant irrespective of the zone, and it is possible to obtain

15 good overwriting characteristics within a wide linear velocity range completely covering a linear velocity of from 3 to 8 m/s, by changing only α_1 and α_i depending upon the zone.

Preferably, numerical values of these Pe/Pw, Pb, Pw,

20 β_m, (α^1_1, α^p_1), and (α^1_c, α^p_c) are preliminarily recorded on the substrate by prepits or groove deformation, whereby it is possible to select the best pulse-dividing method and the best power for driving, for every recording medium or for every zone. Such numerical

25 values may usually be recorded at positions adjacent to the inner-most peripheral edge or the outer-most peripheral edge of the record region. If bias power Pb

is made to be the same as retrieving power Pr, bias power Pb may not necessarily be recorded in some cases. The groove deformation may specifically be, for example, groove wobbling (wobbles).

5   Otherwise, to an optical information recording medium having an address information preliminarily recorded on the substrate by prepits or groove deformation, an information relating to suitable α_1 and α_i may be included in the address together with the
10   address information.

It is thereby possible to read out the information relating to the pulse-dividing method together with the address information at the time of access and to change the pulse-dividing method, whereby it is possible to
15   select a pulse-dividing method suitable for the recording medium or for the particular zone to which the address belongs, without necessity for any special correction.

The system of carrying out recording over the entire record region of a disk while changing the recording
20   pulse-dividing system for every zone, as described above, is applicable also to a ZCLV system (Zoned CLV). Now, a specific example will be described.

The record region is divided into a plurality of zones in the radial direction, and in each zone,
25   recording is carried out at a constant linear velocity,

the ratio of the recording linear velocity V_{out} in the outer-most diameter zone to the recording linear

velocity V_{in} in the inner-most diameter zone, i.e. V_{out}/V_{in},
is from 1.2 to 2,

α_i=0.3 to 0.6 ($2 \leqq i \leqq m$), and β_m=0 to 1.5, and

m, $\alpha_i + \beta_{i-1}$($3 \leqq i \leqq m$), $\alpha_1 T$, Pe/Pw and Pb are constant
5   irrespective of the linear velocity, and α_i ($2 \leqq i \leqq m$)
and/or β_m is changed depending upon the linear velocity.

The ZCLV system is the same as the ZCAV system so
far as the division of the recording region radially into
a plurality of zones is concerned, but within the same
10   zone, recording is carried out by a CLV mode i.e. by
rotating the disk at a constant linear velocity.

Therefore, when the recording method of the present
invention is applied to this ZCLV system, the difference
between V_{in} and V_{out} is made small, e.g. V_{out}/V_{in} being from
15   1.2 to 2, whereby the load of the linear velocity
dependency to the medium is reduced.

The medium of the present invention is recordable
within a wide linear velocity range of from 3 to 8 m/s
simply by slightly modifying the recording pulse-dividing
20   method. Accordingly, the ZCLV system can be used,
wherein the record region is divided into a relatively
small number of zones.

At that time, in order to make the recording density
to be equal irrespective of the zone, the linear velocity
25   V_q in each zone, and the reference clock period T_q of
record data in each zone are adjusted so that $T_q<V_q>_{ave}$
will be substantially constant irrespective q.

And, in each zone, the optimized recording pulse-dividing method is employed. Namely, α_i=0.3 to 0.5 ($2 \leqq i \leqq m$), and β_m=0 to 1.5, and recording is carried out by changing α_1 and/or β_m depending upon the linear velocity while maintaining m, $\alpha_i + \beta_{i-1}$ ($3 \leqq i \leqq m$), $\alpha_1 T$, Pe/Pw and Pb to be constant irrespective of the linear velocity.

In the above described CLV system, ZCAV system or ZCLV system, the example for making the recording pulse-dividing method variable depending upon the linear velocity during overwriting is intended to simplify the pulse-generating circuit mainly by making β_m to be constant irrespective of the linear velocity. Inversely, it is also possible to simplify the pulse-generating circuit by positively changing β_m.

Namely, the present invention provides an optical information recording method which comprises recording information by a plurality of record mark lengths, wherein the shortest mark length is at most 0.5 µm, and a crystal state is an unrecorded or erased state and an amorphous state is a recorded state, and wherein a recording laser beam having an erasing power Pe capable of crystallizing amorphous phase is applied between record marks, and

when the time length of one record mark is represented by nT (wherein T is the reference clock period, and n is an integer of at least 2), the time length nT of the record mark is divided in the order of:

$\eta_1 T$, $\alpha_1 T$, $\beta_1 T$, $\alpha_2 T$, $\beta_2 T$, . . .,

$\alpha_i T$, $\beta_i T$, . . ., $\alpha_m T$, $\beta_m T$, $\eta_2 T$

wherein m is a pulse dividing number, and m=n-k, where k

is an integer of $0 \leqq k \leqq 2$,

5    $\Sigma_i (\alpha_i + \beta_i) + \eta_1 + \eta_2 = n$, η_1 is a real number of $\eta_1 \geqq 0$, η_2

is a real number of $\eta_2 \geqq 0$, provided $0 \leqq \eta_1 + \eta_2 \leqq 2.0$,

$\alpha_i (1 \leqq i \leqq m)$ is a real number of $\alpha_i > 0$, $\beta_i (1 \leqq i \leqq m)$ is

a real number of $\beta_i > 0$,

$\alpha_1 = 0.1$ to 1.5, $\beta_1 = 0.5$ to 1.0, $\beta_m = 0$ to 1.5, and when

10   i is $2 \leqq i \leqq m$, α_i is within a range of from 0.1 to 0.8 and

is constant irrespective of i, and

when i is $3 \leqq i \leqq m$, $\alpha_i + \beta_{i-1}$ is within a range of from

0.5 to 1.5 and is constant irrespective of i,

a recording laser beam having a writing power Pw of

15   Pw>Pe, sufficient to melt the recording layer, is applied

within the time of $\alpha_i T$ $(1 \leqq i \leqq m)$, and a recording laser

beam having a bias power Pb of $0 < Pb \leqq 0.2Pe$ is applied

within the time of $\beta_i T (1 \leqq i \leqq m)$ (provided that within $\beta_m T$,

the bias power may be $0 < Pb \leqq Pe$), and

20   while maintaining m, $\alpha_i + \beta_{i-1} (3 \leqq i \leqq m)$, $\alpha_1 T$ and

$\alpha_i T (2 \leqq i \leqq m)$ to be constant irrespective of the linear

velocity, β_m is changed so that it simply increases as

the linear velocity is small.

Firstly, in order to maintain the recording density

25   to be constant, the above described ZCAV system or the

ZCLV system is applied, so that the reference clock

period T changes in inverse proportion to the linear

velocity.

And when i is at least $3 \leqq i \leqq m$, preferably $2 \leqq i \leqq m$, $\alpha_i + \beta_{i-1}$ is made to be constant irrespective of the linear velocity and i, whereby the pulse-generating circuit can be simplified, and it is possible to increase the cooling rate of the recording layer simply by reducing α_i as the linear velocity is low. Usually, $\alpha_i + \beta_{i-1} = 1.0$.

In order to realize such a pulse-dividing method, referring to the view illustrating the timing for the gate generation in Figure 11, one fixed length pulse with a width of $\alpha_1 T$ (Gate 1) and a plurality of subsequent fixed length pulses with a width of $\alpha_i T$ ($\alpha_c T$) (Gate 2) may be generated, while only Gate 3 determining the final off pulse length $\beta_m T$ may be changed depending upon the linear velocity.

Here, the following conditions are preferred:

$Pw_{max} / Pw_{min} \leqq 1.2$,

$Pe/Pw = 0.4$ to 0.6,

$0 \leqq Pb \leqq 1.5$ (mW)

where Pw_{max} is the maximum recording power and Pw_{min} is the minimum recording power, at each recording linear velocity.

Further, as described above, at least in a case where the linear velocity during overwriting is at most 5 m/s, in order to prevent a thermal damage during repetitive overwriting, it is preferred that $\Sigma \alpha_i < 0.4n$ when m=n-1, and $\Sigma \alpha_i < 0.5n$ when m=n-2.

Further, a recording method may be employed wherein when β_m at the maximum recording linear velocity is represented by β^H_m and β_m at the minimum recording linear velocity is represented by β^L_m, β_m at other recording
5   linear velocities is a value between β^L_m and β^H_m, and Pb and Pe/Pw are constant irrespective of the recording linear velocity.

In this case, it is preferred that numerical values of at least Pe/Pw ratio, Pb, Pw, α_1T, α_iT, (β^L_m, β^H_m)
10   are preliminarily recorded on the substrate of the medium by prepits or groove deformation, whereby an optimum pulse-dividing method can automatically be selected.

Furthermore, an optical recording method is also possible wherein β_m is constant irrespective of the
15   recording linear velocity, while maintaining adequately practical signal quality, if the maximum linear velocity is up to twice the minimum linear velocity.

For a read-only DVD drive of a CLV system, a system is available wherein rotation control is carried out by
20   generating a data clock and a rotation synchronizing signal based on the reference clock period obtained by retrieving marks.

As described above, a medium on which marks are recorded by a ZCAV system so that the shortest mark
25   length or the channel bit length is substantially constant irrespective of the recording radius, can be retrieved as it is by a read-only DVD drive of this

system.

Namely, rotational synchronizing control can be made by a PLL (Phase Lock Loop) system so that the reference clock period T_q' of data formed from the recorded marks
5 will substantially agree with the reference data clock Tr of the drive, whereby even if slight sway of the linear velocity or the channel bit length is present, decoding can be made by the retrieving circuit as it is.

Especially, for EFM plus modulated data recorded so
10 that the shortest mark length is substantially constant at 0.4 μm in all zones, CLV rotation synchronization by PLL control can be accomplished based on the rotation synchronizing signal formed from the recorded marks. At the same time, the reference data clock Tr having a
15 frequency within a range of from 25 to 27 MHz will be generated, and based on this clock, retrieving can be made as a CLV recording medium without need to pay attention to the transfer among zones.

Of course, if rotation synchronization can be
20 accomplished so that the standard data clock becomes Tr/2, retrieving at 2-times velocity will be possible. Such rotation synchronizing signal-generating circuit, etc., by PLL system may be those commonly used in conventional DVD players or DVD-ROM drives.

25 The medium of the present invention is able to secure retrieving interchangeability with DVD with respect to all signal characteristics except for the

reflectance. For this purpose, in-groove recording is preferred, and the push-pull signal of the groove should preferably be small. If the push-pull signal of the groove is large, the tracking servo signal in the DPD

5 method to be used for retrieving, tends to be small. Accordingly, the groove depth is required to be shallower than $\lambda/(8n)$ at which the push-pull signal becomes maximum. Here, λ is the wavelength of the retrieving laser beam in air, and n is the refractive index of the

10 substrate. However, during recording, it is common to use a push-pull signal for tracking servo. Accordingly, it is not desirable that the signal is too small.

Further, with respect to the retrieving signal characteristics, the modulation Mod is preferably at

15 least 0.5 in order to obtain a high CN ratio. Here, Mod is (amplitude of envelope of DC retrieving signal)/(top value of envelope of DC retrieving signal).

A preferred groove depth is d=$\lambda/(20n)$ to $\lambda/(10n)$. If the depth is shallower than $\lambda/(20n)$, the push-pull

20 signal during recording tends to be too small to be detected by a tracking servo. On the other hand, if it is deeper than $\lambda/(10n)$, tracking servo during retrieving can not be stabilized. For example, the groove depth is preferably within a range of from 25 to 40 nm, when the

25 recording or retrieving wavelength is at a level of from 630 to 670 nm, and the numerical aperture NA of the object lens is from 0.6 to 0.65.

Further, in order to secure a capacity equivalent to DVD, the groove pitch is adjusted to be from 0.6 to 0.8 µm. Further, when the groove pitch is adjusted to be 0.74 µm, it is easy to secure interchangeability with DVD.

The groove width is preferably from 0.25 to 0.5 µm. If it is narrower than 0.25 µm, the push-pull signal tends to be too small. If it is wider than 0.5 µm, the width between grooves becomes narrow, whereby a resin tends to hardly penetrate during the injection molding of the substrate, and accurate transfer of the groove shape to the substrate tends to be difficult.

With the medium of the present invention, the reflectance decreases after recording. With such a recording medium, it is preferred to make the groove width narrower than the land width in order to make the reflectance in the groove to be low i.e. to attain RGa<RLa, where RGa is the average reflectance in the groove after recording, and RLa is the average reflectance of the land after recording.

For example, in order to secure interchangeability with DVD, if the groove pitch is adjusted to 0.74 µm, the groove width is preferably narrower than 0.37 µm which is one half of the groove pitch.

On the other hand, in a case where the average reflectance RGb in the groove before recording may be larger than the average reflectance RLb on the land before recording i.e. RGb>RLb, so long as the above

RGa<RLa is satisfied, it may sometimes be possible to reduce jitter, to increase the modulation or to widen the width of amorphous marks to be recorded in the groove, by adjusting the groove width to be from 0.4 to 0.5 μm.

5   To such a groove, a periodical deformation may be provided to access an unrecorded specific track or to obtain a synchronizing signal for rotating the substrate at a constant linear velocity. Usually, a wobble may be provided, which wobbles in the transverse direction of

10   the track. Namely, if the groove is wobbling at a certain constant frequency f_{wo} , by detecting the frequency, it is possible to take out the signal for rotation synchronization by the PLL system.

The amplitude of the groove wobbling is preferably

15   from 40 to 80 nm (peak-to-peak value). If it is less than 40 nm, the amplitude is too small, and the SN ratio tends to be poor, and if it exceeds 80 nm, the upper and lower edges of the envelope of the recording signal shown in Figure 6 contain many low frequency components

20   attributable to the wobble signal, whereby the distortion of the retrieving signal tends to be large.

When the frequency of wobbling is close to the zone of the record data, its amplitude is preferably at most 80 nm.

25   Further, if wobbling is formed which is frequency modulated or phase modulated in accordance with a certain address information using the wobbling frequency f_{wo} as a

carrier wave, it is possible to obtain the address
information by retrieving it.

If groove wobbling is formed with the wobbling
frequency f_{wo} being constant, it is possible to generate

5   a reference clock signal for data from a reference period
T_w of the groove wobbling signal formed from f_{wo} or from
its multiple or divisor.

Usually, the wobbling period is set to have a
sufficiently low frequency or high frequency than the

10   frequency component of data to prevent mixing with the
data signal component and to be able to readily separate
by a zone filter or the like. Particularly, it has
already been practiced for recordable CD that f_{wo} is set
to be lower by one of two figures than the reference

15   clock period of data.

With a medium to be used for a CLV system, after
accomplishing PLL rotation synchronization, a data
reference clock is formed by multiplying f_{wo} by about one
to two figures. A data reference clock formed by such a

20   method is usually likely to accompany fluctuation of the
same order as the data reference clock (frequency), by
the influence of the fluctuation of rotation
synchronization (about 0.1 to 1% of f_{wo}). This tends to
deteriorate the window margin for detecting data.

25   Therefore, it is also effective to insert a prepit
or a special wobble having a large amplitude for every
predetermined data length to correct the fluctuation of

the data reference clock, separately from the groove
wobbling signal. On the other hand, if f_{wo} is at a level
of the data reference clock frequency (1/T) or within a
range of from 1/100 to 100 times thereof, even if the
5 data reference clock is generated as it is on the basis
of the wobbling signal taken out after rotation
synchronization, an adequate degree of precision can be
secured. Namely,

$$100/T \geqq f_{wo} \geqq 1/(100T) \qquad (5)$$

10 Further, in the ZCAV method as described above, the
reference clock period T_q is preferably generated as a
multiple or a divisor of the reference period Tw_q of the
groove wobbling in each zone. Namely, by forming a
groove wobbling at a constant angular velocity while
15 changing the frequency f_{wo} for every zone, it is possible
to generate a reference clock formed as f_{wo} or its
multiple frequency, as the reference clock T_q for data.

At that time, if the groove wobbling is made to be a
relatively high frequency wave to satisfy the formula (5),
20 formation of the data reference clock for every zone will
be easy. And, it is possible to change the reference
clock T_q for every zone and to generate a variable pulse-
dividing method to synchronize with this signal, whereby
the positional precision of each divided pulse can be
25 improved, and fluctuation can be reduced, such being
desirable.

As an example for division of zones for the ZCAV

system, one round of the groove may be taken as one zone.
Here, if the groove is wobbling with a constant period
irrespective of the zone, and the following relation is
approximately satisfied:

5      $2\pi \cdot TP = a \cdot Tw_0 \cdot V_0$

where TP is the groove pitch, Tw_0 is the wobbling period,
and a is a natural number, wobbling having a constant
period Tw_0 will be formed over the entire record region,
and for every one round of track, the number of wobbles
10   will increase by a.

And, Tw_0 being a multiple of the reference clock
period T, i.e. $Tw_0 = mT$ (where m is a natural number),
means that a reference clock may be generated from Tw_0
simply by dividing it by the multiple, whereby the
15   reference clock-generating circuit can be simplified,
such being desirable. In such a case, m may not exactly
be a natural number, and a deviation from a natural
number to an extent of ±5% may be allowable.

Namely, when TP=0.74 μm, if v_0=3.5 m/s, T=38.23 nsec,
20   and n=1, $m \doteqdot 34.7$. If the wobbling period is
approximately taken as $Tw_0 = 35T$, the number of wobbles
increases by one for every one round.

In such a case, wobble phases of adjacent tracks are
always coherent even though wobbles are introduced by a
25   CLV system. Thus, there is a merit that fluctuation in
the retrieving amplitude of the wobbling signal due to
interference (beat of wobbles) is small.

In the foregoing, some applications of the present invention have been described, and the present invention is effective to improve the recording power dependency and the linear velocity dependency in mark length

5 recording of phase change media in general and is not limited to rewritable DVD.

For example, the medium and the recording method of the present invention are effective also in a case where mark length modulation recording with the shortest mark

10 length being at most 0.3 μm is carried out by means of an optical system having NA = at least 0.6 and a blue color laser beam with a wavelength of from 350 to 500 nm. The shortest mark length is preferably at least about 10 nm, taking the stability of mark into consideration.

15 In such a case, it is necessary to pay an attention to flatten the temperature distribution in the transverse direction of the track, and it is effective to reduce the thickness of the second protective layer to be very thin at a level of from 5 to 15 nm.

20 When a laser beam having a wavelength of 350 to 400 nm is employed, the thickness of the second protective layer is more preferably made to be at most 10 nm.

Further, the medium of the present invention may be applied to so-called land and groove recording wherein

25 recording is carried out on both the land and the groove. Such a recording system is suitable for high density recording, since it is easy to make the track pitch

narrower while maintaining the groove width broad,
although there is a difficulty in satisfying equal
recording characteristics in both the land and groove.
By adjusting both the groove width GW and the land width

5   LW to be from 0.2 to 0.4 μm, it is possible to obtain a
constant tracking servo performance while attaining high
density. If the ratio of GW/LW is from 0.8 to 1.2,
signal qualities of both the land and groove can be
maintained to be equivalent. To reduce cross talk, the

10   groove depth d should preferably be from $\lambda/(7n)$ to
$\lambda/(5n)$ or from $\lambda/(3.5n)$ to $\lambda/(2.5n)$.

EXAMPLES

Now, the present invention will be described in
further detail with reference to Examples. However, it

15   should be understood that the present invention is by no
means restricted to such specific Examples.

In the following Examples, the substrate was
prepared by injection molding. The substrate was an
injection molded polycarbonate resin substrate having a

20   thickness of 0.6 mm, and unless otherwise specified, a
groove having a groove pitch of 0.74 μm, a width of 0.34
μm and a depth of 30 nm were spirally formed thereon.

Unless otherwise specified, the groove had a wobble
having a frequency of 140 kHz at a linear velocity of 3.5

25   m/s, and the amplitude of the wobble was about 60 nm
(peak-to-peak value).

The shape of the groove was measured by means of a

U-groove approximate optical diffraction method. The
shape of the groove may be actually measured by a
scanning electron microscope or by a scanning probe
microscope. In such a case, a groove width at the
5   position corresponding to one half of the groove depth,
is employed.

Unless otherwise specified, a four layer structure
as shown in Figure 5(a) was formed on the substrate, and
then a protective layer made of an ultraviolet curable
10 resin was formed thereon by spin coating. The laminate
thereby obtained was bonded to another substrate of 0.6
mm in thickness having the same layer structure. In the
following Examples and Comparative Examples, the first
protective layer in Figure 5(a) will be referred to as
15 the lower protective layer, and the second protective
layer will be referred to as the upper protective layer.

The recording layer immediately after the film
formation was amorphous, and it was irradiated with light
with an initializing power of from 500 to 700 mW by means
20 of a laser beam with a wavelength of from 810 to 830 nm,
focused to have a long axis of about 90 μm and a short
axis of 1.3 μm and by selecting a proper linear velocity
within a range of from 3.0 to 6.0 m/s, to melt and
recrystallize the entire surface to an initial
25 (unrecorded) state.

The compositions of the respective layers were
confirmed by a combination of e.g. fluorescent X-ray

analysis, atomic absorption analysis and X-ray-excited photoelectron spectrometry.

The film density of the recording layer or the protective layer was obtained from the weight change,
5 when it was formed into a film as thick as a few hundreds nm on the substrate. The film thickness obtained from the fluorescent X-ray intensity was used by correcting it with the film thickness measured by a tracer.

The sheet resistivity of the reflective layer was
10 measured by a four probe resistivity meter (Loresta FP, trade name, manufactured by Mitsubishi Petrochemical Co., Ltd. (presently Dia Instruments)).

The resistivity was measured with a reflective layer formed on glass or polycarbonate resin substrate as an
15 insulator, or with a reflective layer constituting the uppermost layer after formation of the four layer structure (before protective coating with an ultraviolet curable resin) as shown in Figure 5.

The upper protective layer was a dielectric thin
20 film which is an insulator, and therefore even with the four layer structure, there is no influence over the measurement of the sheet resistivity of the reflective layer. Further, measurement was made in the form of a disk substrate having a diameter of 120 mm, which can be
25 regarded substantially as having an infinite area. From the obtained resistance value R, the sheet resistivity ρs and the volume resistivity ρv were calculated by the

following formulae:

$$\rho S = F \cdot R \qquad (6)$$

$$\rho v = \rho s \cdot t \qquad (7)$$

Here, t is the layer thickness, and F is a

5 corrective factor determined by the shape of the thin
film region and takes a value of from 4.3 to 4.5. Here,
F was taken to be 4.4.

Unless otherwise specified, for the evaluation of
recording and retrieving, DDU1000 evaluation machine,

10 manufactured by Pulstec was employed. The wavelength of
the optical head was 637 nm, and numerical aperture NA of
the object lens was 0.6 or 0.63. The beam diameter was
about 0.90 μm and about 0.87 μm, respectively. Here, the
beam diameter corresponds to the region where by the

15 Gaussian beam, the energy density becomes at least $1/e^2$
of the peak intensity.

For the recording, the pulse-dividing method shown
in Figure 10 was employed, wherein unless otherwise
specified, m=n-1, and $\alpha_1 + \beta_{i-1} = 1.0$ ($2 \leqq i \leqq$ m). At every

20 linear velocity, Pb was constant at 1.0 mW which was the
same as the retrieving power. Pe/Pw was constant at 0.5,
unless otherwise specified. Modulation and jitter were
measured by changing Pw while maintaining Pb to be
constant between 0.8 and 1.0 mW.

25 Signals to be recorded were 8-16 modulated (EFM plus
modulation) random signals which are commonly used for
DVD. Further, unless otherwise specified, measurement

was carried out in a state where only one single track
was recorded, and there was no influence of cross talk.

Recording was carried out at various linear
velocities such as 1-time velocity and 2-times velocity,
5   based on the standard linear velocity of 3.5 m/s for DVD
being regarded as 1-time velocity.

Retrieving was always carried out at a linear
velocity of 3.5 m/s, and jitter was measured after the
retrieving signal after passed through an equalizer, was
10 digitized. Here, the jitter means edge-to clock jitter
and is represented by % based on reference clock period T.
The characteristics of the equalizer were as prescribed
in read-only DVD standard. It is desired to obtain a
modulation of at least 50%, preferably at least 60% and
15 jitter of less than 10% (preferably less than 8%) of
reference clock period T=38.2 nsec. (26.16 MHz). Further,
it is desired that there is little increase of jitter
after repetitive overwriting, and less than 13% to T is
maintained even after at least 100 times, preferably even
20 after 1,000 times, of repetitive overwriting.

With a view to securing interchangeability with
read-only DVD, measurement with a retrieving laser beam
with a wavelength of from 650 to 660 nm is important.
However, in the present invention, wavelength is not
25 critical as it merely slightly influences over the shape
of the focused laser beam. It was confirmed that the
same level of jitter as attained by the 637 nm optical

system as used in the present invention, can be obtained also with a 660 nm optical system.

EXAMPLE 1 AND COMPARATIVE EXAMPLE 1

To compare, as recording layers, the conventional InAgSbTe four component system and the InGeSbTe system of the present invention, media were prepared as shown in Table 1, wherein the recording layer compositions and the layer structures were substantially strictly unified except that Ag and Ge were replaced.

With the two recording layers, the compositions were substantially equal within a range of measuring errors, except that Ag and Ge were replaced. The thicknesses of the lower protective layers were different, to adjust the reflectance Rtop of the media to be the same. Such correction is necessary since the refractive indices of the recording layers are delicately different. In order to compare by bringing the light absorbing efficiency of the recording layers to be the same and by bringing the influence of thermal damage due to the retrieving laser beam to be the same, this is a necessary correction. Since the recording layer thickness and the upper protective layer thickness are the same, they can be regarded as equal with respect to the heat dissipation effects and the thermal damages.

The substrate was a polycarbonate resin having a thickness of 0.6 mm, and was provided with a groove with a groove pitch of 0.74 μm, a groove width of 0.34 μm, a

groove depth of 27 nm, a wobble frequency of 140 kHz
(linear velocity: 3.5 m/s) and a wobble amplitude of 60
nm (peak-to-peak value), and recording was carried out in
the groove.

5   To the above two types of media, EFM plus modulated
recording was carried out at a recording linear speed of
3.5 m/s with T=38.2 nsec, whereby good overwrite
recording characteristics were shown. The overwrite
recording conditions were selected so that the
10   characteristics of the two would be substantially equal
as shown in Table 1 rather than the conditions under
which the respective disk characteristics became best.

       Namely, in a recording pulse-dividing method as
shown in Figure 10(a), m=n-1, $\alpha_i + \beta_{i-1} = 1.0$ ($2 \leqq i \leqq m$), $\alpha_i =$
15   α_c=constant ($2 \leqq i \leqq m$), $\alpha_1 = 0.5$, $\alpha_c = 0.3$ and $\beta_m = 0.5$, and
Pw=13.5 mW, Pe=6.5 mW and Pb=0.8 mW.

       To the signals thus recorded, the retrieving laser
beam was repeatedly applied to examine the retrieving
laser beam stability. After irradiation with a
20   predetermined retrieving laser power Pr for a
predetermined number of times, jitter, etc., were
measured while sufficiently lowering the retrieving power
to a level of 0.5 mW. The results are shown in Figure 12.

       The medium of Example 1 showed no deterioration by
25   the retrieving laser beam up to 10^6 times with the
retrieving laser power of 1 mW. When the power was
increased stepwise by 0.1 mW every time, the

deterioration was gradually quickened.

On the other hand, with the medium of Comparative Example 1, jitter increased sharply during the period from the initial 100 times to 1,000 times by retrieving laser beams with retrieving laser powers of at least 1 mW, and then gradually deteriorated. Jitter values are high as a whole, but the initial deterioration of jitter is fatal.

Further, in Comparative Example 1, the modulation decreased by the retrieving laser beam. It decreased by about 10% by irradiation of about 100 times, and then was stabilized. At the initial stage, it is considered that jitter increases sharply, and that the decrease of the modulation proceeds non-uniformly.

The recorded media of Example 1 and Comparative Example 1 were left to stand in an environment of 80°C/80% relative humidity to carry out accelerated tests. After 250 hours, the performance of the disk of Example 1 did not substantially change, while the recorded signals of the disk of Comparative Example 1 disappeared substantially completely. It is evident that with the recording layer material having the composition of Comparative Example 1, amorphous marks are extremely unstable.

As shown above, the disk of Example 1 is excellent not only in the initial overwrite recording performance but also in the stability against retrieving laser beam

and the stability with time. This indicates that in the alloy system containing excess Sb in $Sb_{0.7}Te_{0.3}$, the addition of a suitable amount of Ge is very effective.

The medium of Example 1 was subjected to an
5 accelerated test under an environment of 80°C/80% relative humidity. The accelerated test was carried out up to 200 hours. Deterioration of jitter of signals recorded before the acceleration test was only about 1%.

Further, the modulation was 64% at the initial stage,
10 and showed no substantial change at 61% after 2,000 hours of the accelerated test. The reflectance was also not substantially changed. When recording was carried out anew to an unrecorded portion after 2,000 hours, deterioration of jitter was about 3%, but such a level is
15 practically not problematic.

Further, with respect to the medium of Example 1, the recording pulse-dividing method dependency of jitter was studied in detail with respect to a case where m=n-1 and m=n-2.

20 Figure 13 is a contour map showing the α_i and α_c dependency of jitter when recording was carried out at a linear velocity of 3.5 m/s with (a) m=n-1 and (b) m=n-2.

Further, Figure 14 is a contour map showing the α_1 and α_c dependency of jitter when recording was carried
25 out at a linear velocity of 7.0 m/s with (a) m=n-1 and (b) m=n-2, respectively. Pw, Pe, Pb and β_m used in the measurement of each Figure are shown above each Figure.

It is evident that at a linear velocity of 3.5 m/s, in either case of m=n-1 or m=n-2, the lowest jitter (about at most 7%) is obtained in the vicinity of $\alpha_1=0.7$ to 0.8 and $\alpha_c=0.35$ to 0.40.

5   At a linear velocity of 7.0 m/s, in either case of m=n-1 or m=n-2, the lowest jitter is obtained in the vicinity of $\alpha_1=0.5$ and $\alpha_c=0.40$. With respect to α_1 and α_c in the vicinity of which the lowest jitter is obtainable, in each case, a condition of $\Sigma \alpha_i<0.5n$ is

10   satisfied.

In this Example, in either case of a linear speed of 3.5 m/s or 7.0 m/s, a lower jitter value is obtained by setting m=n-2, and as compared with the case of m=n-1, a low jitter value is obtained even with a large α_1.

15   Further, the medium of Example 1 was subjected to evaluation of the linear velocity dependency of jitter by means of an evaluation machine with NA=0.63, by changing the recording pulse-dividing method as shown in Table 2. The reference clock period T was in inverse proportion to

20   the linear velocity. The pulse-dividing method was such that m=n-1, $\alpha_i+\beta_{i-1}=1.0$ ($2 \leqq i \leqq m$), and $\alpha_i=\alpha_c=$constant ($2 \leqq i \leqq m$). Pw, Pb and Pe were constant irrespective of the linear velocity. Here, by the pulse-dividing method of Table 2, $\Sigma \alpha_i<0.5n$ is satisfied at all linear

25   velocities.

Good overwrite performance was obtained in a range of from 1-time velocity to 2.5-times velocity of the

standard linear velocity of DVD. This medium shows good overwrite performance over the entire recording region even by a CAV system, by dividing the recording region into 3 or 4 zones and by slightly modifying the recording pulse strategy for every zone.

Further, similar results were obtained even when the recording and retrieving were conducted with a wavelength of 660 nm by means of an evaluation machine with NA=0.65.

EXAMPLE 2

On the substrate, a lower protective layer $(ZnS)_{80}(SiO_2)_{20}$, a recording layer $Ge_{0.05}Sb_{0.73}Te_{0.22}$, an upper protective layer $(ZnS)_{80}(SiO_2)_{20}$ and a reflective layer $Al_{0.995}Ta_{0.005}$, were formed by changing the thicknesses of the respective layers variously. The thicknesses of the respective layers are shown in Table 1. All layers were prepared by a sputtering method without releasing vacuum.

The reflective layer was formed at a film-deposition rate of 1.3 nm/sec at a final vacuum pressure of not higher than 2×10^{-4} Pa under an Ar pressure of 0.54 Pa.

The volume resistivity was 55 $n\Omega \cdot m$, and the sheet resistivity was 0.28 $\Omega / \square$.

Impurities such as oxygen, nitrogen, etc., were below the detective level by X-ray-excited photoelectron spectrometry, and the sum of all impurities can be regarded as substantially less than 1 atomic %. The film density of the protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 3.50

g/cm^3, which was 94% of the theoretical bulk density of 3.72 g/cm^3. Further, the density of the recording layer was 90% of the bulk density. The thermal conductivity of the protective layer estimated from the thermal

5   simulation was 3.5×10^{-4} pJ/(μm·K·nsec).

On the medium thus prepared, recording (overwriting) was carried out at a speed of 1-time velocity and 2-times velocity of DVD, respectively, by using the pulse-dividing method shown in Figure 10(a), as optimized for

10   every layer structure of each medium. Thereafter, jitter was measured after overwriting once, 10 times and 1,000 times. For the measurement, an optical system with a wavelength of 637 nm and NA=0.63, was employed for both recording and retrieving.

15   In Table 3, the optimum pulse-dividing method for each layer structure, jitter, Rtop and the modulation were summarized.

In every case, at a speed of 1-time velocity, it was possible to conduct a mark length modulation recording

20   with the shortest mark length of 0.4 μm and obtain a large initial modulation.

When the upper protective layer thickness was adjusted to be 20 nm, each of the initial jitter and the jitter after 1,000 times overwriting was less than 10%.

25   When the upper protective layer thickness was adjusted to be 30 nm, although the initial jitter was good, the jitter a little increased by repetitive overwriting, for

example, increased to from 10 to 12% after 1,000 times overwriting. When the upper protective layer thickness was 40 nm, initial jitter was at least 13% and rapidly deteriorated by repetitive overwriting to a level of at least 20%.

Further, as is evident from Example 2(h2), if the recording layer thickness was as thick as 30 nm, initial recording jitter was substantial at a level of at least 13%, and deterioration of jitter by repetitive overwriting was remarkable.

From Example 2(i2), it is evident that even if the lower protective layer thickness is thin at a level of 45 nm, the repetitive overwriting durability is poor.

Further, when the thickness of the reflective layer was 250 nm, jitter was better than the thickness being 200 nm. Namely, it is evident that in such high density mark length recording, it is preferred to adopt "ultra rapid cooling structure".

Then, with respect to the medium of Example 2(g1), the recording power Pw dependency of jitter was evaluated. Recording was carried out at 1-time velocity and 2-times velocity by employing the pulse-dividing method shown in Figure 10 wherein $m=n-1$, $Pw=14$ mW, $Pe/Pw=0.5$ and $\beta_m=0.5$. Thereafter, the dependency of jitter on α_1 and $\alpha_c=\alpha_i$ ($2\leq i\leq m$) was evaluated.

At 2-times velocity, $\alpha_1=0.5$, $\alpha_c=0.4$, $\beta_m=\beta_{n-1}=0.5$, $Pw=14$ mW, and at 1-time velocity, $\alpha_1=0.7$, $\alpha_c=0.3$,

$\beta_m = \beta_{n-1} = 0.5$ and Pw=14 mW. At that time, at 2-times velocity, $\Sigma \alpha_1 = 0.3n$ (n=3), 0.33n (n=4), 0.34n (n=5) and at most 0.38n (n=6 to 14). At 1-time velocity, $\Sigma \alpha_1 = 0.33n$ (n=3), 0.33n (n=4), 0.32n (n=5) and less than 0.32n (n=6 to 14).

The results are shown in Figure 15. The recording power Pw dependency of jitter after the first and 10 times of overwriting, and the recording power Pw dependency of reflectance Rtop and modulation Mod, after 10 times of overwriting, are shown. Figure 15(a) shows the result of 2-times velocity recording, and Figure 15(b) shows the result of 1-time velocity recording. Rtop corresponds to Itop in Figure 6. Further, in the Figure, DOW (Direct Overwriting) indicates overwriting.

Then, the overwriting durability was evaluated. The results are shown in Figure 16. With respect to jitter, the reflectance and the modulation, the respective values up to after 1,000 times of overwriting are shown. Figure 16(a) shows the results of 2-times velocity recording, and Figure 16(b) shows the results of 1-time velocity recording. In either case, jitter gradually increased up to about 10 times, but was stabilized after 10 times, and all of the jitter, the modulation and the reflectance did not substantially deteriorate up to 1,000 times.

Further, this medium was subjected to overwriting by the same pulse-dividing method as the above 2-times velocity (linear velocity of 7 m/s) with Pw=14 mW except

that the linear velocity was 9 m/s, and the reference clock period was 14.9 nsec. The erasing ratio was adequate at a level of at least 30 dB. Further, jitter was good at a level of less than 11%.

5   With the medium of Example 2(g1), good jitter was obtained by changing only α_1 and α_c while maintaining Pw=14 mW, Pb=1 mW, Pe/Pw=0.5 and $\beta_m=0.5$ to be constant within the linear velocity range of from 3 to 8 m/s. Namely, good jitter of less than about 9% was obtained by
10   changing the conditions to three steps such that at a linear velocity of from 3 to 5 m/s, $\alpha_1=0.7$ and $\alpha_c=0.35$, at a linear velocity of from 5 to 7 m/s, $\alpha_1=0.65$ and $\alpha_c=0.4$ and at a linear velocity of from 7 to 8 m/s, $\alpha_1=0.55$ and $\alpha_c=0.45$. It is believed that better jitter
15   can be obtained by changing α_1 and α_c more finely for every 1 m/s at each linear velocity.

Further, with Pw=11 to 14 mW, the best jitter was obtained at a ratio of Pe/Pw of from 0.4 to 0.5. Further, when Pb exceeds 1.5 mW, jitter abruptly deteriorated.
20   Here, with Pe/Pw=0.5, the Pb dependency was examined, whereby substantially the best jitter was obtained when Pb was less than 1.0 mW. Namely, Pb/Pe must be less than 0.2.

Now, Example 2(g1) wherein the upper protective
25   layer thickness was 20 nm and Example 2(d2) wherein the upper protective layer thickness was 40 nm, will be compared. With respect to both media, the recording mark

length dependency was measured as follows at 1-time velocity.

Employing an optical system with NA=0.6, the length of 3T mark as the shortest mark was decreased from 0.5 μm

5   in EFM plus modulation, whereby the mark length dependency of jitter was evaluated. The recording linear velocity was constant at 3.5 m/s, and the pulse-dividing method was constant as described above. By changing the reference clock period, the mark length was changed.

10 However, in the case where the shortest mark length was at least 0.46 μm, from the restriction from the apparatus, CLV control tends to be difficult at a retrieving velocity of 3.5 m/s, and the retrieving velocity was adjusted to be 5 m/s. Further, the shortest mark length

15 of 0.4 μm corresponds to read-only DVD standard.

The results are shown in Figure 17. Figure 17(a) represents the medium of Example 2(g1), and Figure 17(b) represents the medium of Example 2(d2).

It is evident that the medium of Example 2(g1) is

20 useful as the jitter is less than 13% up to the shortest mark length of about 0.38 μm.

Further, when an optical system with NA=0.63 was employed, it was possible to reduce jitter to a level of about 2%. Further, when the equalizer at the time of

25 retrieving was optimized, it was again possible to reduce the jitter to a level of about 2%. In addition, it is believed that if an optical system with NA=0.65 is

employed, sufficiently good jitter may be obtained even
with 0.35 μm.

With the medium of Example 2(d2), jitter was no
problematic level with a mark length of at least 0.45 μm.
However, with a mark length of less than 0.45 μm, jitter
abruptly increased, and with a mark length of 0.40 μm,
jitter became at least 13%, and such was practically
useless.

Then, to evaluate so-called tilt margin, EFM plus-
modified random pattern signals were recorded on the
medium of Example 2(g1) over a plurality of tracks, and
then the substrate was intentionally inclined to the
optical axis of the retrieving laser beam, whereby the
change of jitter during retrieving was measured. The
optical system for recording and retrieving had NA=0.6,
the recording linear velocity was 1-time velocity or 2-
times velocity, and in each case, retrieving was carried
out after 10 times of overwriting. The measured results
are shown in Figure 18. The tilt margin was ±0.7 to 0.8
degree in the radial direction, and ±0.5 to 0.6 degree in
the circumferential direction, which were no problematic
level for usual drive.

Accelerated test

EFM plus-modified random pattern was recorded on a
part of the track of the medium of Example 2(g1) with
Pw=13 mW employing the above-mentioned optimum pulse-
dividing method. Thereafter, this medium was subjected

to an accelerated test under a high temperature high
humidity condition of 80°C/80% relative humidity. After
500 hours and 1,000 hours of the accelerated test, the
jitter of the track was measured again, whereby jitter

5   was found to have deteriorated only by 1% after the 1,000
hours.

Further, after 1,000 hours of the accelerated test,
the random pattern was recorded on another track under
the same conditions as above, whereupon jitter was

10   measured, whereby deterioration at a level of 2% was
observed, but such a level is practically no problematic.

Furthermore, recording was carried out similarly at
a speed of 1-time velocity and 2-times velocity, and
modulations before and after accelerated test for 1,000

15   hours under a high temperature high humidity condition of
80°C/80% relative humidity were evaluated. At the speed
of 1-time velocity, the initial modulation was 61% and
the modulation after the accelerated test was 58%. At
the speed of 2-times velocity, the initial modulation was

20   60% and the modulation after the accelerated test was 58%.

Stability against retrieving laser beam

The retrieving laser beam was applied to the medium
of Example 2(g1) by increasing the power to 1.2 mW, but
no deterioration was observed at a level of 10 minutes.

25   Then, with the power of 1.0 mW, the retrieving laser beam
was repeatedly irradiated up to 1,000,000 times, but
increase of jitter was less than 2%.

EXAMPLE 3

A medium was prepared with the same layer structure as in Example 2 except that the composition of the recording layer was changed to $Ge_{0.05}Sb_{0.71}Te_{0.24}$. The

5   thicknesses of the respective layers and the evaluation results are shown in Table 4. For the measurement, an optical system with NA=0.63 was used.

Like in Table 3, in the respective layer structures, α_1, α_c and β_{n-1} were optimized, and Pw and Pe were set so

10   that jitter would become minimum, whereupon jitter was evaluated.

Like in Example 3(a), in Example 2(a1), good performance was obtained at the recording linear velocity of 1-time velocity and 2-times velocity. However, at 9

15   m/s, jitter was higher by from 1 to 2% than Example 2(a1).

Further, in Examples 3(a) to 3(f) wherein the upper protective layer thickness was 30 nm, jitter of less than 10% was obtained, and even after 100 times of overwriting, jitter was less than 13%. In Examples 3(g) to 3(i)

20   wherein the upper protective layer thickness was as thick as 40 nm, jitter was always larger than 13%.

EXAMPLE 4

The layer structure was such that a lower protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 215 nm in thickness, a recording

25   layer $Ge_{0.05}Sb_{0.69}Te_{0.26}$ was 18 nm, an upper protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 18 nm, and a reflective layer $Al_{0.995}Ta_{0.005}$ was 200 nm. The composition of the recording

layer was one whereby good characteristics were obtainable by recording at a linear velocity of from 3 to 5 m/s and was one for so-called 1-time velocity. However, the amount of excess Sb is slightly smaller than Examples

5 1 and 2, and it is therefore excellent in archival life and is preferred when an emphasis is placed on the storage stability of recorded information or the durability against deterioration by repetitive retrieving, i.e. durability against retrieving laser beam.

10 The following evaluation was carried out by an optical system with NA=0.6. Determination of the optimum pulse-dividing method was carried out as follows. At a recording linear velocity of 3.5 m/s, Pw=13 mW and Pe/Pw=0.5, and in Figure 10, α_1 and α_c were changed

15 while maintaining β_m=0.5 to be constant, whereby a pulse-dividing method whereby the minimum jitter was obtainable, was selected. In Figure 19, the α_1 and α_c dependency of jitter after 10 times of overwriting is shown as a contour map of jitter. By setting α_1=0.4 to

20 0.8 and α_c=0.3 to 0.35, substantially the best jitter was obtained. Accordingly, based thereon, α_1=0.6 and α_c=0.35 were selected. At that time, $\Sigma \alpha_i$=0.32n (n=3), 0.33n (n=4), 0.3n (n=5) and less than 0.35n (n=6 to 14).

The modulation was 65%, which is a value comparable

25 to read-only DVD. Rtop was at a level of 23%, but if it is practically at least 15%, retrieving by a conventional read-only drive may be possible.

Therefore, an image data was recorded on the recording medium of the present invention with Pw=12.5 mW at a linear speed of 3.5 m/s, and retrieving was driven by a commercially available read-only DVD player, whereby

5 with respect to the focus servo, tracking servo signal and jitter, characteristics equivalent to usual read-only DVD, were obtained.

Repetitive overwriting durability

Figure 20 shows the dependency of jitter, Rtop and

10 modulation on the number of times of repetitive overwriting with Pw=12.5 mW. It shows sufficiently stable characteristics even after at least 1,000 times of overwriting.

Accelerated test

15 EFM plus modified random pattern was recorded on a part of the track of the medium with Pw=13 mW employing the above described optimum pulse-dividing method, and jitter was measured. Thereafter, this medium was subjected to an accelerated test under a high temperature

20 high humidity condition of 80°C/80% relative humidity. After 500 hours and 1,000 hours of the accelerated test, jitter of this track was measured again, whereby jitter was found deteriorated only by less than 0.5% after 1,000 hours.

25 Further, after 1,000 hours of the accelerated test, the random pattern was recorded on another track under the same conditions as above, and jitter was measured,

whereby deterioration at a level of 1% was observed, but
such a level is practically not problematic.

Stability against retrieving laser beam

5   The retrieving laser beam was applied to this medium
by increasing the power to 1.3 mW, but no deterioration
was observed at a level of 10 minutes. Then, with the
power of 1.0 mW, the retrieving laser beam was irradiated
up to 1,000,000 times, but increase of jitter was less
than 1%.

10   EXAMPLE 5

      In the layer structure of Example 2(a1), the
recording layer was changed to $Ge_{0.05}Sb_{0.75}Te_{0.20}$. The
evaluation was carried out by an optical system with
NA=0.6.

15   The best jitter was obtained with α_1=0.4, α_c=0.3,
β_m=0.5, Pw=14 mW and Pe/Pw=0.5. Jitter after ten times
of overwriting was slightly less than 10%, and even after
1,000 times, jitter of less than 13% was maintained.

Accelerated test

20   EFM plus-modified random pattern was recorded on a
part of the track of this medium with Pw=14 mW employing
the above described optimum pulse-dividing method, and
jitter was measured. Thereafter, this medium was
subjected to an accelerated test under a high temperature
25   high humidity condition of 80°C/80% relative humidity.
After 500 hours of the accelerated test, jitter of the
track was measured again, but jitter was found

deteriorated only by 2%.

Further, after 500 hours of the accelerated test, the random pattern was recorded on another track under the same conditions as above, and jitter was measured, 5 whereby deterioration of a level of about 3% was observed, but such a level is practically not problematic.

Stability against retrieving laser beam

The retrieving laser beam was applied to this medium by increasing the power to 1.0 mW, but no deterioration 10 was observed at a level of 10 minutes with the power of 1.0 mW. The retrieving laser beam was repeatedly irradiated up to 1,000,000 times, but increase of jitter was less than 3%, and jitter of less than 13% was maintained.

15 EXAMPLE 6

In the layer structure of Example 4, the recording layer was changed to $Ag_{0.05}Ge_{0.05}Sb_{0.67}Te_{0.23}$. Evaluation was carried out by an optical system with NA=0.6.

At a linear velocity of 3.5 m/s, the pulse-dividing 20 method dependency (α_1 and α_c) of jitter was measured with Pw=13 mW, Pe/Pw=0.5, m=n-1 and β_m=0.5, whereby a contour map as shown in Figure 21(a) was obtained. The best result was obtained with α_1=0.6, and α_c=0.35. In this case, $\Sigma\alpha_1$=0.32n (n=3), 0.33n (n=4), 0.33n (n=5) and 25 less than 0.35n (n=6 to 14).

Figure 21(b) shows the power dependency of jitter after once, ten times and 1,000 times of overwriting, and

Figure 21(c) shows the power dependency of Rtop and
modulation after ten times of overwriting. Good jitter
was maintained within a wide recording power range up to
after 1,000 times of overwriting. Further, Rtop of 18%
5   and a modulation of at least 60% were accomplished.

Figure 22 shows the changes in jitter, Rtop and
modulation after 1,000 times of overwriting with Pw=13 mW.
No deterioration was observed except that jitter
increased about 1% at the initial stage.

10   Further, in the same manner as in Example 1, the
shortest mark length dependency of jitter was measured,
and the results are shown in Figure 23. With the
shortest mark length of 0.38 μm, jitter was extremely
good at a level of less than 10%.

15   Further, with respect to this medium, evaluation was
carried out on a pulse-dividing method where m=n-2,
whereby characteristics similar to Figure 21 were
obtained with $\alpha_1=1.0$, $\alpha_c=0.5$ and $\beta_m=0.5$. At n=3,
$\Sigma \alpha_i=0.48n$, at n=4, $\Sigma \alpha_i=0.48n$ and at n≧5, $\Sigma \alpha_i=0.46n$ to
20   0.47n.

COMPARATIVE EXAMPLE 2

In the layer structure of Example 6, the recording
layer was changed to $Ag_{0.05}In_{0.05}Sb_{0.63}Te_{0.27}$.

The pulse-dividing method dependency of jitter was
25   evaluated with Pw=13 mW, Pe/Pw=0.5 and $\beta_m=0.5$, whereby a
contour map as shown in Figure 24(a) was obtained. The
best results were obtained at $\alpha_1=1.0$ and $\alpha_c=0.5$. In this

case, $\Sigma \alpha_i$ was constant at 0.5n irrespective of n.

The recording power dependency and repetitive overwriting characteristics up to 1,000 times are shown in Figures 24(b) and (c). Jitter after first recording and the power margin were better than in Example 5, but deteriorated by repetitive overwriting. After 1,000 times, jitter was rather poor.

Further, the retrieving laser power was raised to 1 mW, whereby jitter deteriorated in five minutes and increased to ten and a few %. This difference can not be explained by the difference of the recording sensitivity from 0.5 to 1 mW. The main factor for the deterioration by the retrieving laser beam is that the temperature rises to a level of from 50 to 100°C, and it is evident that addition of Ge of the present invention is effective for the improvement of the thermal stability of amorphous marks.

COMPARATIVE EXAMPLE 3

The layer structure was such that a lower protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 90 nm in thickness, a recording layer $Ge_2Sb_2Te_5$ was 21 nm, an upper protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 23 nm, and a reflective layer $Al_{0.995}Ta_{0.005}$ was 200 nm.

For the recording, on the basis of the pulse-dividing method shown in Figure 10(a), fine adjustments were carried out so that the best jitter was obtainable with respect to each mark length and each linear velocity.

With this medium, as shown in Figure 25, the best jitter was obtained with a strategy such that $\alpha_1 = \alpha_c = \alpha_0 = 0.3$ to 0.4 and constant, and $\beta_m = 1.0$. Further, Pw=13 mW, Pe/Pw=0.4 (Pe=5 mW) and Pb=2.0 mW were the optimum

5   powers. The ratio of Pb/Pe=0.4 is slightly high, but with the recording layer of this Cooperative Example, this is necessary to maintain TL in Figure 9 at a high level to some extent.

When Pb was less than 1 mW, jitter was poor, but

10   also when Pb was at least 3 mW, jitter again deteriorated.

On the basis of this pulse-dividing method, the mark length dependency was measured in the same manner as in Example 2 by carrying out a precise pulse width adjustment at a level of 0.02 to α_0 depending upon the

15   mark length. The results are shown in Figure 26(a). Further, the linear velocity dependency during overwriting was measured. The results are shown in Figure 26(b).

For the linear velocity dependency, the reference

20   clock period was changed depending upon the linear velocity, so that the shortest mark length became 0.4 μm, and retrieving was carried out always at 3.5 m/s. With respect to the linear velocity dependency, jitter after ten times of overwriting and jitter after erasing DC,

25   followed by one overwriting operation, were recorded.

As shown in Figure 26(a), at the shortest mark length of 0.4 μm, jitter was 10%, and when the shortest

mark length became shorter, jitter deteriorated abruptly.

Further, as shown in Figure 26(b), jitter deteriorated at a recording linear velocity of at least 5 m/s. However, in the recording after DC erasing, jitter

5 is lower by from 2 to 3%. This indicates that due to non-uniformity in the temperature rise due to difference in absorptivity between the so-called crystal state and the amorphous state, failure in erasing or distortion of the amorphous mark shape resulted, whereby jitter

10 deteriorated.

After overwriting at a linear velocity of 7 m/s, jitter was at least 20%, but in recording after DC erasing, it was about 15%. Accordingly, the reason for the high jitter at a high linear velocity is considered

15 to be not attributable that a proper pulse-dividing method was not selected.

This recording layer contained coarse grains, and therefore, jitter was high. In addition, at a linear velocity of at least 5 m/s, erasing of the previous marks

20 during overwriting tends to be inadequate, and its influence clearly appears as a difference in jitter from recording after DC erasing.

Further, the difference in jitter as between a case where overwriting was carried out at 7 m/s on the above

25 medium of Example 2(g1) and a case where recording was carried out after DC erasing, was less than 0.5%.

In the case of a recording medium employing a

recording layer of a GeTe–Sb_2Te_3 pseudo binary alloy such as $Ge_2Sb_2Te_5$, with the four layer structure comprising protective layer/recording layer/protective layer/reflective layer, at a high linear speed of from 5 to 6 m/s, there is no problem in recording after DC erasing, as mentioned above, but jitter deteriorates during overwriting. Therefore, to reduce jitter, it is necessary to take a additional measure such as to correct absorptivity by adding a light absorptive layer.

COMPARATIVE EXAMPLE 4

In Example 2(g1), recording layer was changed to $Ge_{0.15}Sb_{0.64}Te_{0.21}$. Initial crystallization was very difficult, and the initialization beam was irradiated a plurality of times for initialization, and then subjected to overwriting, whereupon jitter was measured. However, even if the pulse-dividing method was changed within the range of Figure 10, it was not possible to obtain jitter of 13% or lower. Further, if repetitive overwriting was continued, jitter increased by a few % between ten times and 100 times.

COMPARATIVE EXAMPLE 5

In the layer structure of Example 2(g1), the recording layer was changed to $Ge_{0.05}Sb_{0.80}Te_{0.15}$. At 7 m/s, substantially the best jitter was obtained with $\alpha_1 = 0.4$, $\alpha_c = 0.3$, $\beta_m = 0.5$, Pw=14 mW, Pe/Pw=0.5, but jitter was slightly below 11% after ten times of overwriting, and increased to at least 13% after 1,000 times.

Accelerated test

EFM plus modified random pattern was recorded on a part of the track of this medium with Pw=14 mW employing the above-mentioned optimum pulse-dividing method, and

5 jitter was measured. Thereafter, this medium was subjected to an accelerated test under a high temperature high humidity condition of 80°C/80% relative humidity. After 500 hours of the accelerated test, jitter of this track was measured again, whereby jitter was found

10 deteriorated by about 3% and became at least 13%.

Further, after 500 hours of the accelerated test, the random pattern was recorded on another track under the same conditions as above, and jitter was measured, whereby a deterioration of about 5% was observed, and

15 thus the deterioration was quick.

Stability against retrieving laser beam

To this medium, the retrieving laser beam was applied by increasing the power up to 1.0 mW, whereby jitter increased by 3% after 10 minutes and was very

20 unstable. Further, the modulation decreased, and there was a tendency that the marks disappeared.

EXAMPLE 7

To the medium of Example 2(a1), EFM plus signals were recorded at a speed of from 1-time velocity (3.5 m/s,

25 reference clock period T=38.2 nsec) to 2.25-times velocity (7.9 m/s, T=17 nsec) by maintaining $\alpha_1 T = \tau_1 = 19$ nsec and $\alpha_c T = \tau_c = 11$ nsec to be constant at every linear

velocity and changing only T in inverse proportion to the linear speed. Further, β_i which will be constant in $\alpha_i + \beta_{i-1} = 1.0$, was determined. Further, only the final off pulse section β_m was changed so that it became long as

5 the linear velocity was slow.

In such a pulse-dividing method, in the view illustrating the gate-generation timing in Figure 11, one fixed length pulse of $\tau_1 = 19$ nsec (Gate 1) and n-2 fixed pulses of $\tau_c = 11$ nsec (Gate 2) may be generated by

10 synchronizing to the reference clock period T (a predetermined delay may be added), and further only Gate 3 for determining the final off pulse length may be changed depending upon the linear velocity, such being preferred as the pulse-generating circuit can be

15 simplified. Further, in this Example, recording power Pw=13.5 mW, Pe=5 mW and Pb=0.5 mW are constant at these levels, whereby the pulse-generating circuit can be very simplified. Here, if the linear velocity is at most 5 m/s, $\Sigma \alpha_i < 0.47n$ is satisfied. Thus, thermal damage was

20 sufficiently suppressed.

In Table 5, values of jitter obtained by changing β_m at various linear velocities, are summarized. In the Table, v indicates a standard velocity of 3.5 m/s. The wavelength of the pickup was 637 nm and NA=0.63. The

25 values of jitter themselves are, as in Example 2, slightly poor as compared with the case where the pulse-dividing method was varied more flexibly, but values of

substantially less than 10% are obtained from 1-time velocity to 2.25-times velocity.

Here, if β_m is changed in reverse proportion to the linear velocity by setting $\beta^H_m=0.3$ at the 2-times

5 velocity and $\beta^L_m=0.6$ at the 1-time velocity (the point surrounded by square), it is evident that jitter of less than 10% is obtainable from 1-time velocity to 2-times velocity. Further, in this Example, the margin of β_m is small, but even if β_m is set to be constant at 0.2,

10 jitter of less than 10% can be obtained from 1-time velocity to 2.25-times velocity. Also in this manner, a pulse-generating circuit variable by the linear velocity can be simplified.

Further, if Pb, Pe/Pw, Pw, τ_0, τ_c and (β^L_m, β^H_m) are

15 preliminarily recorded on the recording medium by prepits or by modulated groove wobbling signals, optimum recording conditions can be automatically determined depending on the linear velocity at the time of overwriting.

20 EXAMPLE 8

The layer structure was such that a lower protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 215 nm in thickness, a recording layer $Ge_{0.05}Sb_{0.69}Te_{0.26}$ was 19 nm, an upper protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 20 nm, and a reflective layer

25 $Al_{0.995}Ta_{0.005}$ was 200 nm.

At a linear velocity of 3.5 m/s, recording was carried out by a pulse-dividing method being $\alpha_1=0.5$,

α_c=0.35, β_m=0.5, Pw=11 mW, Pe=6.0 mW, Pb=0.5 mW and by changing the reference clock period T to change the shortest mark length (3T mark length) from 0.4 μm to 0.25 μm. When the mark length of 3T mark was 0.4 μm, T=38.2 nsec, and when it was 0.2 μm, T=19.1 nsec. The wavelength of the recording laser was 637 nm, and NA=0.63.

This focused laser beam had a Gaussian distribution, whereby it is possible to record at a high density of at least the optical resolution by utilizing only the high temperature portion at the center.

The recorded portion was retrieved by a blue laser beam having a wavelength of 432 nm with a power of 0.5 mW and NA=0.6. This laser beam was one generated from a laser beam with a wavelength of about 860 nm by a non-linear optical effect. With this layer structure, a large modulation at a level of at least 50% was obtained even with 432 nm.

Further, in Figure 28, jitter in a case where retrieving was carried out by an optical system with 637 nm and NA=0.63, which was employed for a recording and jitter in a case where retrieving was carried out by an optical system with 432 nm and NA=0.6, were shown as the shortest mark length dependency. In the measurement, the set values of the equalizer were optimized as far as possible at each measuring point. It is evident that with this recording medium, in the blue laser beam retrieving, good jitter of less than 13% is obtained even

with the shortest mark length of 0.3 μm.

COMPARATIVE EXAMPLE 6

In the layer structure of Example 2(a1), the recording layer was changed to $Ge_{0.05}Sb_{0.64}Te_{0.31}$.

5   Recording evaluation was carried out by an optical system with a wavelength of 637 nm and NA=0.63. At a linear velocity of 3.5 m/s, overwriting recording was carried out up to ten times by changing only Pw while maintaining m=n-1, α_1=0.4, α_c=0.4, β_m=0.4, Pb=0.5 mW and

10 Pe=4.5 mW to be constant. The recording power dependency of jitter at that time, is shown in Figure 27(a). In this Figure, 1 write indicates the first recording of an unrecorded disk, 1 DOW indicates the first overwriting, and 10 DOW indicates 10th times overwriting.

15 Then, overwrite recording was carried out up to ten times by changing only Pe while maintaining Pw=8.5 mW to be constant. The erasing power dependency of jitter at that time is shown in Figure 27(b).

In each case, in the first recording (1 write), good

20 jitter was obtained, but when overwriting was carried out even only once, jitter deteriorated abruptly. The composition of the recording layer in this Comparative Example is a Te-rich composition than linear line A in Figure 3, and it is considered that as the

25 crystallization speed is slow, no adequate erasing ratio was obtained, and accordingly no adequate overwriting performance was obtained.

EXAMPLE 9 AND COMPARATIVE EXAMPLE 7

In the layer structure of Example 2(a1), the composition of the recording layer was changed as shown in Table 6. By cosputtering a $Ge_{0.05}Sb_{0.73}Te_{0.22}$ target and
5 Ge, the amount of Ge was changed.

Using an optical system with a wavelength of 637 nm and NA=0.63, the conditions under which jitter after ten times of overwriting becomes minimum, were investigated by changing α_1, α_c, Pw and Pe while maintaining m=n-1,
10 Pb=0.5 mW and β_m=0.5.

The minimum jitter obtained by the composition of each recording layer was as shown in Table 6. As the amount of Ge increased, jitter increased, and when Ge was 10 atomic % or more, jitter at 2-times velocity became
15 very high at a level of 14%.

Further, this medium was subjected to an accelerated test under conditions of 80°C/80% relative humidity, whereby Examples 9(b) and (c) were slightly better than Example 9(a). Namely, signals recorded before the
20 accelerated test were retrieved after 2,000 hours of the accelerated test, whereby in either case of Examples 9(a) to (c), the jitter deteriorated only by 1%.

Further, in Examples 9(a) to (c), the initial modulation was from 61% to 63% and, even after the
25 accelerated test of 2,000 hours, the modulation obtained was from 58% to 59%. The reflectance were not substantially changed. Especially, in Examples 9(b) and

(c), there was an increase within 0.5%.

Then, by cosputtering a $Ge_{0.05}Sb_{0.73}Te_{0.22}$ target and Ta, the amount of Ta was added. As a result, optimum jitter was obtained when from 1 to 2 atomic % of Ta was added to

5 GeSbTe.

EXAMPLE 10 AND COMPARATIVE EXAMPLE 8

In the layer structure of Example 2(g1), the recording layer was changed to GeSbTe having In added. In was added by cosputtering InSbTe to a GeSbTe target.

10 The compositions of the respective recording layers were $Ge_{0.05}Sb_{0.74}Te_{0.21}$ in Example 10(a), $In_{0.023}Ge_{0.048}Sb_{0.719}Te_{0.21}$ in Example 10(b), $In_{0.053}Ge_{0.044}Sb_{0.688}Te_{0.215}$ in Example 10(c), and $In_{0.118}Ge_{0.041}Sb_{0.617}Te_{0.224}$ in Comparative Example 8.

The power dependency of jitter of the respective

15 media was evaluated, and the results are shown in Figures 29(a), (b), (c) and (d). The upper section represents a case where the recording linear velocity was 3.5 m/s, and the lower section represents a case where it was 7.0 m/s.

In each case, the optical system employed had 637 nm

20 and NA=0.63. In the case of a linear velocity of 3.5 m/s, $\alpha_1=0.6$, $\alpha_c=0.35$ and $\beta_m=0.5$, and in the case of 7.0 m/s, $\alpha_1=0.4$, $\alpha_c=0.4$ and $\beta_m=0.5$. Pb was constant at 0.5 mW. Pe was constant at two levels, and only Pw was changed to measure the Pw dependency of jitter. By the addition of

25 In in an amount of from 2 to 5 atomic %, the Pw margin was improved to a large extent. However, when it exceeded 10 atomic %, jitter became poorer than a case

where In was not added.

Further, the jitter after 1,000 times of overwriting was less than 10% at both linear velocities in Examples 10(a) to (c), but it was higher than 13% at both linear velocities in Comparative Example 8.

Accelerated test

The medium of Example 10(b) was subjected to an accelerated test under an environment of 80°C/80% relative humidity. The accelerated test was carried out until 2,000 hours. Deterioration of jitter of signals recorded before the accelerated test was only about 1%.

Further, the initial modulation was 61%, and even after 2,000 hours of accelerated test, the modulation obtained was 57%. The reflectance was not substantially changed.

After 2,000 hours, recording was carried out anew on an unrecorded portion, whereby deterioration of jitter was about 3%, but such a level is not practically problematic.

EXAMPLE 11

In the layer structure of Example 2(g1), the recording layer was changed to $In_{0.03}Ge_{0.05}Sb_{0.71}Te_{0.21}$, and such a disk was formed on a polycarbonate resin substrate having the groove shape as identified in Table 7. In each case, the groove pitch was 0.74 μm.

As a wobble-modulated system, a binary phase modulation was employed wherein the period T_w of a

carrier wave was 32 times of reference data clock period T=38.2 nsec. Here, the phase modulated wobble is such that as shown in Figure 30, the phase of the wobble wave is shifted by π in correspondence with 0 or 1 of a

5 digital data signal.

Namely, a non-modulated carrier wave (cosine wave or sine wave) having a frequency $f_c=1/T_w=1/(32T)$ will shift by a phase π by switching a digital data for address from 0 to 1 or from 1 to 0. The switching period T_d of

10 digital data 0 and 1 is of a low frequency than T_w, and T_d is a divisor of T_w, and accordingly, even if the phase has shifted, the wobble wave form is continuously changed.

This modulation method is preferred in that as is different from frequency (FM) modulation to be employed

15 for ATIP (Absolute Time in Pregroove), the wobbling frequency is constant, and as the period is modulated with a high frequency of 32T, it is possible to establish rotational synchronization of the disk with reference to the wobbling clock and at the same time to form a data

20 clock directly in synchronization with the wobbling clock.

To change the phase by modulation of a digital data like this, a ring modulator as shown, for example, in Figure 31, may be employed. For the digital data, a positive or negative voltage ±V is applied in

25 correspondence with 0 or 1. At the time of preparing a stamper, exposure is carried out while a laser beam for exposure of a photoresist is wobbled in the radial

direction in accordance with a wobble wave form binary phase modulated between voltages of $\pm V_w$. At that time, by applying the output wave of a ring modulator to an EO modulator, the exposure beam can be wobbled.

5   Now, this will be described in further detail. In the Figure, if a signal of $V_w \cdot \cos(2\pi f_c t)$ having a frequency of $\cos(2\pi f_c t)$ is input to the non-modulated carrier wave input terminal, two carrier wave signals of $V_w \cdot \cos(2\pi f_c t)$ and $-V_w \cdot \cos(2\pi f_c t)$ will appear as output of

10   the input transformer. If the digital data input is positive $(+V)$, D_1 and D_1' are conducted, and the carrier wave $V_w \cdot \cos(2\pi f_c t)$ passes through D_1, and modulation appears at the output terminal. The carrier wave of $-V_w \cdot \cos(2\pi f_c t)$ passes through D_1', then is inverted by a

15   transformer on the output side and becomes $V_w \cdot \cos(2\pi f_c t)$, and it is then added to the output passed through D_1, to obtain an output of $V_w \cdot \cos(2\pi f_c t)$.

If the digital data input is negative $(-V)$, i.e. if D_2 and D_2' are conducted, the signal of $V_w \cdot \cos(2\pi f_c t)$ is

20   led to a lower side of an output side transformer via diode D_2, whereby at the output terminal, the modulation is inverted and becomes $-V_w \cdot \cos(2\pi f_c t)$.

On the other hand, the carrier wave which was $-V_w \cdot \cos(2\pi f_c t)$ at the output side of the input side

25   transformer will be added to the common mode input of the output side transformer via diode D_2', and it thus appears with the same polarity (as $-V_w \cdot \cos(2\pi f_c t)$) at the

modulated wave output terminal. Accordingly, the carrier waves passed through the passages of diodes D_2 and D_2' will be combined as $-V_w \cdot \cos(2\pi f_c t)$, and the modulation appears at the output end.

5   In the case of a ring modulator, $V_w \cdot \cos(2\pi f_c t)$ or $-V_w \cdot \cos(2\pi f_c t)$ will be output at the output terminal depending upon whether the digital data input is positive or negative.

       The wobble waveform thus modulated will be input to
10   an EO modulator, whereby the exposure beam can be wobbled.

       In this Example, the wobble amplitude was 60 nm (peak-to-peak value) in all cases.

       In the case of a medium wherein recording is carried
15   out only in a groove, the recording or retrieving laser wavelength $\lambda = 637$ nm and the refractive index of the substrate n=1.56, whereas a preferred range of the groove depth is such that lower limit is $\lambda/(20n) = 20.5$ nm, and the upper limit is $\lambda/(10n) = 40.8$ nm.

20   For the evaluation of this medium, an optical system with a wavelength of 637 nm and NA=0.63 was used.

       As in Example 2, by a recording pulse-dividing method with m=n−1, $\alpha_i + \beta_{i-1} = 1.0$ ($2 \leq i \leq m$) and $\alpha_i = \alpha_c =$ constant ($2 \leq i \leq m$), at a linear velocity of 3.5 m/s,
25   $\alpha_i = 0.5$, $\alpha_c = 0.3$, $\beta_m = 0.5$, Pw=13 mW and Pe=6 mW, and at a linear velocity of 7 m/s, $\alpha_i = 0.4$, $\alpha_c = 0.35$, $\beta_m = 0.5$, Pw=14 mW and Pe=7 mW.

Firstly, recording was carried out in a groove at a linear velocity of 3.5 m/s, and Rtop and the modulation were measured. Further, jitter of the recording signal was measured at 3.5 m/s and at 7 m/s. The results are shown in Table 8.

Firstly, Comparative Example 11(k) had a very shallow groove with a depth of 18 nm, but the push-pull signal was not substantially detected, and it was impossible to apply a tracking servo. Further, preparation of a stamper will be very difficult to form such a shallow groove uniformly. In fact, substantial non-uniformity was observed in the tracking servo signals.

In Figure 32(a) and (b), the groove shape dependency of modulation and Rtop is shown. Examples 11 (h) to (j) have a groove with a depth of 42 nm, but as compared with the case where the depth is 27 nm, the reflectance was substantially low, i.e. lower by at least 5%, such being undesirable. The modulation is low especially in a case where the groove is narrow, and when the width was 0.23 μm, deterioration of the modulation was remarkable even if the depth was 35 nm.

In this Example, the layer structure was the same. However, if, in the case of a depth 42 nm, in order to supplement the deterioration of the reflectance, a layer structure having a high reflectance is adopted, the deterioration of the modulation will be more remarkable. Namely, a groove with a depth of 42 nm is not suitable

for recording in a groove.

If the groove depth is at least 40 nm, when the groove width is less than 0.3 μm, wobble signals will substantially leak into recording data signals. As compared with a case where the groove width is at least 0.3 μm, at a linear velocity of 3.5 m/s, jitter deteriorates by at least 1 to 2%, and at a linear velocity of 7 m/s, jitter deteriorates by 2 to 3%.

EXAMPLE 12

The layer structure was such that a lower protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 65 nm in thickness, a recording layer $Ge_{0.05}Sb_{0.73}Te_{0.22}$ was 16 nm, an upper protective layer $(ZnS)_{80}(SiO_2)_{20}$ was 20 nm, a first reflective layer $Al_{0.995}Ta_{0.005}$ was 40 nm and a second reflective layer Ag was 70 nm.

From the lower protective layer to the first reflective layer, were prepared by sputtering without releasing vacuum. After forming the first reflective layer, vacuum was released and left to stand for a few minutes, and then the second reflective layer was formed by sputtering again in vacuum.

After forming the second reflective layer, an ultraviolet-curable resin was laminated in a thickness of 4 μm as a overcoating layer by spin coating. Two disks obtained in such a manner were bonded so that the overcoating layers faced each other.

Film forming of the first reflective layer was

carried out under a final vacuum pressure of at most 4×10^{-4} Pa under an Ar pressure of 0.55 Pa. The volume resistivity was 55 $n\Omega \cdot m$. Impurities such as oxygen, nitrogen, etc., were below the detectable level by X-ray excited photoelectron spectrometry. The sum of all impurities can be regarded as not higher than about 1 atomic %.

Film forming of the second reflective layer was carried out under a final vacuum pressure of at most 4×10^{-4} Pa under an Ar pressure of 0.35 Pa. The volume resistivity was 32 $m\Omega \cdot m$. Impurities such as oxygen, nitrogen, etc. were below the detectable level by X-ray excited photoelectron spectrometry. The sum of all impurities can be regarded as not higher than about 1 atomic %.

Using an optical system with a wavelength of 637 nm and NA of 0.60, jitter after ten times of overwriting was measured by means of a pulse-dividing method at a linear velocity of 3.5 m/s, with $\alpha_1 = 0.4$, $\alpha_c = 0.35$ and $\beta_m = 0.5$, whereby the minimum jitter of 6.5% was obtained with Pw=11 mW, Pe=6.0 mW, and Pb=0.5 mW.

This medium was left to stand for 500 hours under a high temperature high humidity condition of 80°C/80% relative humidity, and then recording was carried out in the same manner, whereby no deterioration was observed.

EXAMPLE 13

A stamper provided with a spiral groove having a

wobble and having a groove pitch of 0.74 μm, a groove
width of 0.3 μm and a groove depth of 40 nm, was prepared,
and based thereon, a polycarbonate resin substrate having
a diameter of 120 mm and a thickness of 0.6 mm was formed
5 by injection molding.

     As shown in Table 9, 36 mm of a record region was
formed from a radius of 22.5 mm to a radius of 58.5 mm,
and the record region was divided into 255 bands (zones).
Each band contained 191 tracks.

10   The band widths are set so that the final end of
each band will be exactly the 191-st track. Therefore,
each band width is not accurately 36/255. Accordingly,
the outer most final end of the record region is 58.54 mm.

     The channel bit length was 0.133 μm, and at a linear
15 velocity of 3.49 m/s, a reference clock of 26.16 MHz
(T=38.23 nsec) is obtainable. The wobble period was set
so that it became nine times the channel bit length at
the center radius of each band. Its physical period is
1.2 μm.

20   The total number of channel bit lengths and the
total number of wobbles at the center radius of each band
are calculated first, and in the same band, the number of
channel bits or the number of wobbles contained in one
revolution is set to be constant.

25   As shown in Table 9, the number of channel bits or
the number of wobbles is constant with a precision of ±1%
at the first and final ends of the band. Namely, by a

ZCAV system, recording with a constant linear density
which is not different from a CLV system, can be
accomplished by a ZCAV system, and the specifications for
read-only DVD can be fully satisfied.

5   With the foregoing prerequisites, when the disk is
rotated so that a linear speed of 3.49 m/s is obtainable
at the center radius of each band, the wobble period will
be exactly nine times of the reference clock period
T=38.23 nsec of DVD data.

10   This medium is rotated so that the linear velocity
becomes 3.49 m/s at the center radius of the band of the
inner-most band of Table 9, and used as a medium for a
ZCAV system. The period of a carrier wave retrieved from
a wobble of each band under CAV rotation, is multiplied
15   by 1/9 to obtain a data reference clock T_q for each band
and recording of EFM plus modified data is carried out
based on the clock.

At the time of retrieving, if rotational
synchronization can be accomplished so that the data
20   reference clock frequency formed from the recorded data,
will be 26.16 MHz, fluctuation in the channel bit length
in each zone will be less than ±1%, whereby retrieving
can be carried out substantially in a CLV mode without
any trouble.

25   Namely, the above reference clock of 26.16 MHz
(T=38.23 nsec) is generated by a quartz oscillator, and
this phase is compared with the phase of the data

reference clock formed from recorded data, and the rotational speed is finely controlled by a usual PLL (Phase Locked Loop) so that the two will synchronize.

Such a rotation control by PLL control is
5   practically employed for retrieving of DVD-ROM, and it is advantageous that such a system can be used as it is.

EXAMPLE 14

In the layer structure of Example 2(a1), the reflective layer was changed to $Al_{0.975}Ta_{0.025}$. The volume
10 resistivity was 220 $n\Omega \cdot m$. A plurality of samples were prepared by changing the film thickness from 200 nm to 400 nm, and jitter was measured in the same manner as the measurement shown in Table 3 using the respectively optimum pulse-dividing method among Figure 10(a). At the
15 film thickness of about 300 nm, the best jitter of a level of 12% was obtained. When the reflective layer was made thicker or thinner than about 300 nm, jitter deteriorated.

EXAMPLE 15

20 In the layer structure of Example 11(a), the thickness of the upper protective layer was changed to 23 nm.

In-groove recording was carried out to this medium. Using an optical system with a wavelength of 405 nm and
25 NA=0.65, a beam having a substantially circular cross-sectional shape with a spot diameter of about 0.5 μm (diameter at the $1/e^2$ intensity of Gaussian beam) was

formed, and recording and retrieving were carried out via the substrate having a thickness of 0.6 mm.

At a linear velocity of 4.86 m/s, EFM plus modulated signals were recorded with the shortest mark (3T mark) length of 0.25 μm.

Overwriting was carried out ten times by the same recording pulse-dividing method as in Example 2 with m=n-1, α_1=0.5, α_c=0.38 and β_m=0.67, and with Pw=9.5 mW, Pb=0.5 mW and Pe=4.0 mW, whereby jitter was 10%.

It was found that in recording and retrieving with a blue laser, recording of higher quality is possible even when compared with Example 7. Further, a medium designed to meet the current red laser, may be used as it is for recording and retrieving with a blue laser, whereby a high densification can be attained.

EXAMPLE 16

A medium was prepared with the same layer structure as in Example 2(a1) except that the composition of the recording layer was changed to $Ga_{0.05}Ge_{0.05}Sb_{0.68}Te_{0.22}$. Initialization was carried out in the same manner as in Example 2(a1). For the measurement, an optical system with a wavelength of 637 nm and NA=0.63 was used.

At a linear velocity of 3.5 m/s, EFM plus modulated signals were recorded with the shortest mark (3T mark) length of 0.4 μm. Overwriting characteristics were evaluated with the same recording pulse strategy as in Example 2 except that m=n-1, $\alpha_i+\beta_{i-1}=1.0(2\leqq i\leqq m)$,

$\alpha_i = \alpha_c$=constant ($2 \leq i \leq m$) wherein α_1=0.5, α_c=0.3, β_m=0.5, Pw=13.5 mW, Pe=6.0 mW and Pb=0.5 mW. Jitters were as good as 6.9%, 6.7%, 7.0% and 7.3% at the initial recording (non-overwrite), after 10 times overwrite, after 100 times overwrite and after 1,000 times overwrite, respectively.

Further, at a linear velocity of 7.0 m/s, overwriting characteristics were evaluated similarly with α_1=0.4, α_c=0.35, β_m=0.5, Pw=14.0 mW, Pe=7.0 mW, Pb=0.5 mW. The jitters were as good as 7.4%, 7.7%, 8.0% and 8.5% at the initial recording (non-overwrite), after 10 times overwrite, after 100 times overwrite and after 1,000 times overwrite, respectively.

As the modulation, a value of from 55 to 60% was obtained in each case.

This medium was left to stand for 1,000 hours under an accelerated test condition of 80°C/80% relative humidity. Before the test, recording was carried out. The jitter of signals recorded before the accelerated test was worsened by less than 1%. Further, as the modulation, a value of from 52 to 57% was obtained.

EXAMPLE 17

As in Example 2, on a polycarbonate resin substrate having a thickness of 0.6 mm, which was provided with a groove with a pitch of 0.74 µm, a relective layer, a second protective layer, a recording layer and a first protective layer were formed in this order as shown in

Figure 5(b).

These layers were formed by a sputtering method to a thickness of 165 nm for the reflective layer $Al_{0.995}Ta_{0.005}$, a thickness of 20 nm for the second protective layer $(ZnS)_{80}(SiO_2)_{20}$, a thickness of 16 nm for the recording layer $In_{0.03}Ge_{0.05}Sb_{0.70}Te_{0.22}$ and a thickness of 68 nm for the first protective layer $(ZnS)_{80}(SiO_2)_{20}$, respectively.

Then, against the first protective layer, a glass plate having a thickness of 0.6 mm was closely adhered. Intialization was carried out by irradiating a laser beam of about 500 mW at a linear velocity of 5 m/s through a glass substrate.

Through this glass substrate, using an optical system with a wavelength of 637 nm and NA=0.6, recording and retrieving was carried out by irradiating a laser beam to the recording layer. The recording was carried out at a side of unevenness distant from the laser beam incident side. This corresponds to the inside of groove in Example 2.

At a linear velocity of 3.5 m/s, EFM plus modulated signals with the shortest mark 3T length of 0.4 µm was carried out. With the same recording pulse strategy as in Example 2, overwriting characteristics were evaluated provided that m=n-1, $\alpha_i+\beta_{i-1}=1.0(2\leqq i\leqq m)$, $\alpha_i=\alpha_c=$constant$(2\leqq i\leqq m)$ wherein $\alpha_1=0.9$, $\alpha_c=0.35$ and $\beta_m=0.5$, Pw=12.0 mW, Pe=6.0 mW and Pb=0.5 mW. After 10 times overwriting, the jitter was 10.5% and the

modulation was 61%.

Further, at a linear velocity of 7.0 m/s, overwriting characteristics were similarly evaluated provided that $\alpha_1 = 0.55$, $\alpha_c = 0.40$, $\beta_m = 0.5$, $Pw = 13.0$ mW,

5   $Pe = 5.5$ mW and $Pb = 0.5$ mW. After 10 times overwriting, the jitter was 11.2% and the modulation was 61%.

INDUSTRIAL APPLICABILITY

According to the present invention, it is possible to obtain an optical information recording medium having

10   excellent stability of the formed mark with the lapse of time, by which a high speed overwriting can be made and a high density mark length modulation recording with a small jitter of mark edge can be made.

Further, by choosing adequate recording layer

15   composition and layer structure, it is possible to obtain a phase change recording medium which is excellent in the retrieving interchangeability with a read-only medium and high in the durability in repetitive overwriting.

More specifically, it is possible to provide an

20   optical information recording medium which has retrieving interchangeability with a DVD disk and is one beam overwritable within a wide linear velocity range including a standard retrieving velocity of 3.5 m/s to its double velocity of 7 m/s and which shows no

25   deterioration even after at least 10,000 times of overwriting, and an optical recording method.

Further, the medium of the present invention has a

wide linear velocity margin, and even in a case where recording is carried out by rotating the medium at a constant angular velocity by a CAV system or a ZCAV system, the problem of the difference in the recording

5 performance due to the difference in the linear velocity between the inner and outer diameter of the medium, can be overcome. If the CAV system is employed, it is not required to change the rotational speed of the disk for every radial position, and it is possible to shorten the

10 access time.

Table 1

		Example 1	Comparative Example 1
Recording layer material		$In_{0.035}Ge_{0.055}Sb_{0.70}Te_{0.21}$	$In_{0.04}Ag_{0.05}Sb_{0.69}Te_{0.22}$
Sb/Te		3.3	3.1
Thickness (nm)	Lower protective layer	68	74
	Recording layer	16	16
	Upper protective layer	20	20
	Reflective layer	250	250
Recording optical system		637 nm, NA=0.63	
Recording power, etc.		Pw=13.5 mW, Pe=6.5 mW, Pb=0.8 mW	
Recording pulse strategy		$\alpha_1=0.5$, $\alpha_c=0.3$, $\beta_m=0.5$	
Rtop (%)		18.8	18.3
Modulation (%)		64.6	65.4
Jitter (%)		6.7 to 7.0%	6.9 to 7.2%

Table 2

Linear velocity	$\alpha_1/\alpha_c/\beta_m$	Pw/Pe (mW)	Jitter (%)
1.0× (3.5 m/s)	0.6T/0.35T/0.5T	13.5 mW/7.0 mW	5.95
1.5× (5.2 m/s)	0.4T/0.35T/0.5T	13.5 mW/7.0 mW	6.31
2.0× (7.0 m/s)	0.4T/0.4T/0.5T	13.5 mW/7.0 mW	7.57
2.4× (8.4 m/s)	0.5T/0.4T/0.5T	13.0 mW/7.0 mW	8.81

Table 3

Ex. 2	Lower protective layer (nm)	Recording layer (nm)	Upper protective layer (nm)	Reflective layer (nm)	Recording pulse strategy			Pw (mW)	Pe (mW)	Rtop (%)	Modulation (%)	Jitter after 1st recording (%)	Jitter after 10 times of DOW (%)	Jitter after 10 times of DOW (%)
					α_1	α_c	β_{n-1}							
(a1)	64	18	20	200	0.5	0.4	0.5	14	7	17	61	6.9	7.9	8.7
(b1)	64	18	20	200	0.5	0.4	0.5	14	7	18	60	7.1	8.3	8.9
(c1)	64	20	20	200	0.5	0.4	0.5	14	7	16	57	7.6	9.8	9.8
(d1)	64	16	30	200	0.3	0.3	0.6	13.5	6.7	15	65	8.2	9.3	10.2
(e1)	64	18	30	200	0.3	0.3	0.6	13.5	6.7	16	62	8.2	9.9	10.5
(f1)	64	20	30	200	0.3	0.3	0.6	13.5	6.7	17	60	8.2	11.1	11.6
(a2)	64	16	40	200	0.3	0.25	0.9	12	6	12	54	>13	>13	>13
(b2)	64	18	40	200	0.3	0.25	1.3	12.5	6.2	14	51	>13	>13	>13
(c2)	64	20	40	200	0.3	0.25	1.3	13.5	6.7	15	50	>13	>13	>13
(g1)	64	16	20	250	0.5	0.4	0.5	14	7	17	61	6.9	7.5	7.4
(h1)	64	18	20	250	0.5	0.4	0.6	14	7	18	61	6.9	7.8	7.9
(i1)	64	20	20	250	0.5	0.4	0.6	14	7	19	59	6.8	8.7	8.8
(j1)	64	16	30	250	0.3	0.3	0.6	13.5	6.7	14	66	7.5	8.9	9.8
(k1)	64	18	30	250	0.3	0.3	0.6	13.5	6.7	15	65	7.1	9	9.6
(l1)	64	20	30	250	0.3	0.3	0.6	13.5	6.7	16	59	7.3	10.6	11.6
(d2)	64	16	40	250	0.3	0.25	0.8	12.5	6.2	12	61	>13	>13	>13
(e2)	64	18	40	250	0.3	0.25	0.6	12.5	6.7	14	61	>13	>13	>13
(f2)	64	20	40	250	0.3	0.25	1.3	13	6.5	15	54	>13	>13	>13
(m1)	58	18	20	200	0.4	0.4	0.5	14	7	18	61	6.6	8.2	9.1
(n1)	58	20	20	200	0.6	0.4	0.5	14	7	19	59	8.2	10.1	10.6
(o1)	58	18	40	200	0.3	0.3	0.8	12	6	16	58	8.9	11.7	13
(g2)	58	18	40	200	0.3	0.25	1.3	12.5	6.2	14	53	>13	>13	13
(p1)	70	16	20	200	0.5	0.4	0.5	14	7	17	58	7.2	7.9	8.3
(q1)	70	18	30	200	0.5	0.4	0.5	14	7	18	60	6.7	7.8	8.3
(r1)	70	20	40	200	0.5	0.5	0.5	14	7	19	57	6.9	8.5	9
(s1)	70	23	20	200	0.5	0.35	0.5	14	7	24	59	9	9.7	10.5
(h2)	70	30	20	200	0.5	0.35	0.7	(14)	(7)	27	50	>13	>13	>13
(i2)	45	18	20	200	0.5	0.4	0.5	14	7	19	60	7.2	10.5	>13

Table 4

Ex. 3	Lower protective layer (nm)	Recording layer (nm)	Upper protective layer (nm)	Reflective layer (nm)	Recording pulse strategy			Pw (mW)	Pe (mW)	Rtop (%)	Modulation (%)	Jitter after 1st recording (%)	Jitter after 10 times of DOW (%)	Jitter after 100 times of DOW (%)
					α_1	α_c	β_{n-1}							
(a)	64	18	20	200	0.4	0.4	0.4	14	7	17	61	8.7	9.3	9.2
(b)	64	18	20	200	0.4	0.4	0.4	14	7	18	60	8.9	9	9
(c)	64	20	20	200	0.5	0.4	0.4	14	7	18	62	7.9	8.8	9.1
(d)	64	16	30	200	0.3	0.35	0.5	11.5	5.7	15	62	8	9.3	9.7
(e)	64	18	30	200	0.3	0.35	0.6	12	6	16	62	8.4	9.6	10.6
(f)	64	20	30	200	0.3	0.35	0.6	12.5	6.2	16	59	8.1	10.4	11.1
(g)	64	18	40	200	0.3	0.25	0.9	11	5.5	12	55	>13	>13	>13
(h)	64	18	40	200	0.3	0.25	1.3	12	6	14	52	>13	>13	>13
(i)	64	20	40	200	0.3	0.25	1.3	12	6	14.5	51	>13	>13	>13

Table 5

β_m	Jitter (%)			
	2.25-times velocity	2.0-times velocity	1.5-times velocity	1-time velocity
0	10.2	11.9	14.8	18.4
0.1	9.7	10.6	11.4	12.5
0.2	9.8	8.9	9.0	10.0
0.3	11.2	9.5	8.4	8.9
0.4	12.5	10.3	8.2	8.7
0.5	13.7	11.1	8.3	8.7
0.6	>13	>13	8.7	8.7
0.7	>13	>13	>13	9.5

Table 6

	Recording linear velocity (m/s)	α_1	α_c	Pw	Pe	Minimum jitter (%)
Example 9 (a) Ge$_{0.05}$Sb$_{0.73}$Te$_{0.22}$	3.5	0.7	0.35	13.5	6.0	6.0
	7.0	0.5	0.4	13.5	7.0	8.1
Example 9 (b) Ge$_{0.067}$Sb$_{0.717}$Te$_{0.216}$	3.5	0.6	0.35	13.5	6.5	6.2
	7.0	0.4	0.4	13.0	6.5	8.2
Example 9 (c) Ge$_{0.098}$Sb$_{0.693}$Te$_{0.209}$	3.5	0.4	0.3	13.5	6.5	6.6
	7.0	0.3	0.3	14.0	6.5	9.9
Comparative Example 7 Ge$_{0.115}$Sb$_{0.68}$Te$_{0.205}$	3.5	0.4	0.3	13.0	6.5	8.1
	7.0	0.3	0.3	14.0	8.5	14.1

Table 7

	Groove depth (nm)	Groove width (µm)
Example 11(a)	27	0.27
Example 11(b)	27	0.33
Example 11(c)	27	0.42
Example 11(d)	35	0.27
Example 11(e)	35	0.33
Example 11(f)	35	0.42
Example 11(g)	35	0.23
Example 11(h)	42	0.27
Example 11(i)	42	0.33
Example 11(j)	42	0.42
Example 11(k)	18	0.27

Table 8

	Jitter (%) 3.5 m/s	Jitter (%) 7 m/s
Example 11(a)	6.49	7.80
Example 11(b)	5.97	7.62
Example 11(c)	5.52	7.35
Example 11(d)	7.26	8.42
Example 11(e)	6.85	8.39
Example 11(f)	6.05	7.84
Example 11(g)	7.70	8.90
Example 11(h)	9.14	10.49
Example 11(i)	7.66	10.01
Example 11(j)	6.59	9.01
Example 11(k)	Not measurable	

Table 9

Band	Radius (mm) First end of the band	Radius (mm) Final end of the band	Radius at the center of the band (mm)	Circumferential length at the center of the band (mm)	Total number of channel bits at the center of the band	Difference in the channel bit length between the first end and the center of the band — Bit length in the first track	Error (nm)	Error (%)	Difference in the channel bit length between the final end and the center of the band — Bit length in the final end track	Error (nm)	Error (%)	Number of tracks at the final end of the band	Wobble frequency in each band (MHz)
0	22.5000	22.6413	22.57067	141.8157	1063530	132.9268	-0.4065	-0.305%	133.7618	0.4285	0.321%	190	2.9067
1	22.6413	22.7827	22.71201	142.70377	1070010	132.9518	-0.3815	-0.286%	133.7818	0.4484	0.336%	381	2.9249
2	22.7827	22.9240	22.85335	143.59183	1077300	132.8765	-0.4568	-0.343%	133.7008	0.3675	0.276%	572	2.9431
3	22.9240	23.0654	22.99469	144.4799	1083780	132.9014	-0.4319	-0.324%	133.7208	0.3875	0.291%	763	2.9613
4	23.0654	23.2067	23.13603	145.36796	1090260	132.926	-0.4073	-0.305%	133.7406	0.4073	0.305%	954	2.9795
5	23.2067	23.3480	23.27737	146.25603	1096740	132.9504	-0.3829	-0.287%	133.7601	0.4268	0.320%	1145	2.9977
6	23.3480	23.4894	23.41871	147.14409	1103220	132.9744	-0.3589	-0.269%	133.7794	0.4461	0.335%	1336	3.0159
7	23.4894	23.6307	23.56005	148.03216	1110510	132.9012	-0.4321	-0.324%	133.7009	0.3676	0.276%	1527	3.0341
8	23.6307	23.7721	23.70139	148.92023	1116990	132.9253	-0.4080	-0.306%	133.7203	0.3870	0.290%	1718	3.0523
9	23.7721	23.9134	23.84273	149.80829	1123470	132.949	-0.3843	-0.288%	133.7395	0.4062	0.305%	1909	3.0705
10	23.9134	24.0547	23.98407	150.69636	1129950	132.9725	-0.3608	-0.271%	133.7585	0.4252	0.319%	2100	3.0887
→													
100	36.6340	36.7753	36.70467	230.62224	1729350	133.101	-0.2333	-0.174%	133.6145	0.2812	0.211%	19290	4.7269
101	36.7753	36.9167	36.84601	231.51031	1736640	133.0536	-0.2797	-0.210%	133.565	0.2317	0.174%	19481	4.7451
102	36.9167	37.0580	36.98735	232.39837	1743120	133.0685	-0.2646	-0.199%	133.578	0.2447	0.183%	19672	4.7633
103	37.0580	37.1994	37.12869	233.28644	1749600	133.0832	-0.2501	-0.188%	133.5908	0.2575	0.193%	19863	4.7815
104	37.1994	37.3407	37.27003	234.1745	1756080	133.0978	-0.2355	-0.177%	133.6036	0.2703	0.203%	20054	4.7997
105	37.3407	37.4820	37.41137	235.06257	1763370	133.0512	-0.2821	-0.212%	133.5548	0.2215	0.166%	20245	4.8179
106	37.4820	37.6234	37.55271	235.95064	1769850	133.0659	-0.2674	-0.201%	133.5676	0.2343	0.176%	20436	4.8361

Table 9 (continued)

107	37.6234	37.7647	37.69405	236.8387	1776330	133.0804	-0.2529	-0.190%	133.5803	0.2470	0.185%	20627	4.8543
108	37.7647	37.9061	37.83539	237.72677	1782810	133.0943	-0.2385	-0.179%	133.5929	0.2596	0.195%	20818	4.8725
109	37.9061	38.0474	37.97673	238.61483	1789290	133.1091	-0.2242	-0.168%	133.6054	0.2721	0.204%	21009	4.8907
110	38.0474	38.1887	38.11807	239.5029	1796580	133.0633	-0.2700	-0.203%	133.5576	0.2243	0.168%	21200	4.9089
→ 200	50.7680	50.9093	50.83867	319.42878	2395980	133.1333	-0.2000	-0.150%	133.504	0.1707	0.128%	38390	6.547
201	50.9093	51.0507	50.98001	320.31685	2402460	133.1439	-0.1894	-0.142%	133.5135	0.1802	0.135%	38581	6.5652
202	51.0507	51.1920	51.12135	321.20492	2408940	133.1544	-0.1789	-0.134%	133.523	0.1897	0.142%	38772	6.5834
203	51.1920	51.3334	51.26269	322.09298	2415420	133.1648	-0.1685	-0.126%	133.5325	0.1992	0.149%	38963	6.6016
204	51.3334	51.4747	51.40403	322.98105	2422710	133.1307	-0.2026	-0.152%	133.4972	0.1639	0.123%	39154	6.6198
205	51.4747	51.6160	51.54537	323.86911	2429190	133.1411	-0.1922	-0.144%	133.5067	0.1734	0.130%	39345	6.636
206	51.6160	51.7574	51.68671	324.75718	2435670	133.1515	-0.1818	-0.136%	133.5161	0.1828	0.137%	39536	6.6563
207	51.7574	51.8987	51.82805	325.64524	2442150	133.1618	-0.1715	-0.129%	133.5255	0.1922	0.144%	39727	6.6745
208	51.8987	52.0401	51.96939	326.53331	2448630	133.1721	-0.1612	-0.121%	133.5348	0.2015	0.151%	39918	6.6927
209	52.0401	52.1814	52.11073	327.42137	2455920	133.1384	-0.1949	-0.146%	133.5	0.1667	0.125%	40109	6.7108
210	52.1814	52.3227	52.25207	328.30944	2462400	133.1487	-0.1846	-0.138%	133.5094	0.1761	0.132%	40300	6.7291
→ 245	57.1283	57.2696	57.19897	359.39173	2695680	133.1566	-0.1767	-0.132%	133.4861	0.1528	0.115%	46985	7.3661
246	57.2696	57.4110	57.34031	360.27979	2702160	133.166	-0.1673	-0.125%	133.4946	0.1613	0.121%	47176	7.3843
247	57.4110	57.5523	57.48165	361.6786	2708640	133.1753	-0.1580	-0.119%	133.5031	0.1695	0.127%	47367	7.4025
248	57.5523	57.6937	57.62299	362.05992	2715120	133.1845	-0.1488	-0.112%	133.5116	0.1783	0.134%	47553	7.4207
249	57.6937	57.8350	57.76433	362.94399	2722410	133.1541	-0.1792	-0.134%	133.4803	0.1470	0.110%	47749	7.4389
250	57.8350	57.9763	57.90567	363.83205	2728890	133.1633	-0.1700	-0.127%	133.4887	0.1554	0.117%	47940	7.4571
251	57.9763	58.1177	58.04701	364.72012	2735370	133.1725	-0.1608	-0.121%	133.4972	0.1639	0.123%	48131	7.4753
252	58.1177	58.2590	58.16835	365.60819	2741850	133.1817	-0.1516	-0.114%	133.5056	0.1723	0.129%	48322	7.4935
253	58.2590	58.4004	58.32969	366.49625	2748320	133.1908	-0.1425	-0.107%	133.5139	0.1806	0.135%	48513	7.5117
254	58.4004	58.5417	58.47103	367.38432	2755620	133.1607	-0.1726	-0.129%	133.483	0.1497	0.112%	48704	7.5299